Proposal for Detector R&D Towards an EIC Detector

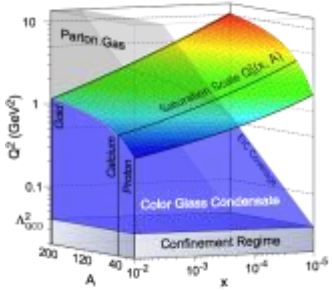
TK Hemmick for the EIC Tracking R&D Group

- Brookhaven National Laboratory
- Florida Institute of Technology
- Iowa State University
- Lawrence Berkeley National Laboratory
- Riken Research Center at BNL
- Stony Brook University
- Temple University
- Thomas Jefferson National Accelerator Facility
- University of Virginia
- Yale University

Most Compelling Physics Questions

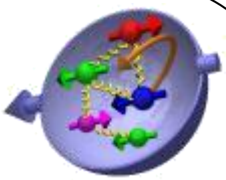
physics of strong color fields

quantitatively probe the universality of strong color fields in AA, pA, and eA



- understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- how do hard probes in eA interact with the medium

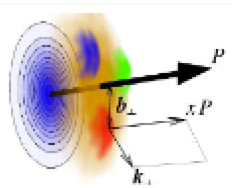
spin physics



- what is the polarization of gluons at low x where they are most abundant
- what is the flavor decomposition of the polarized sea depending on x

determine quark and gluon contributions to the proton spin at last

imaging

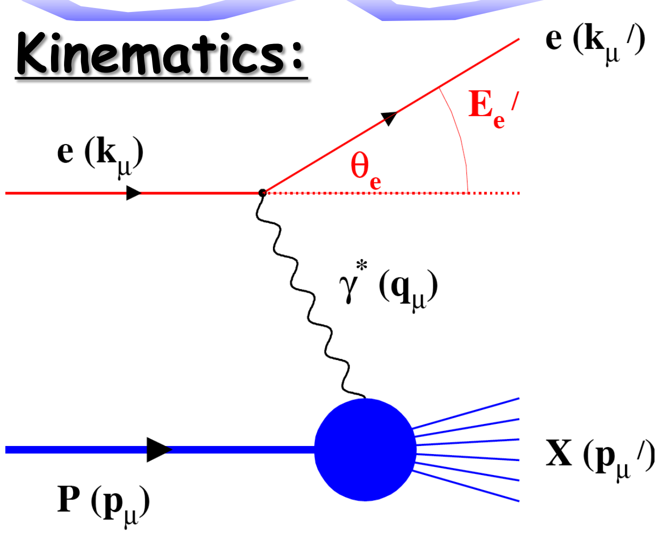


- what is the spatial distribution of quarks and gluons in nucleons/nuclei
- understand deep aspects of gauge theories revealed by k_T dep. distr'n

possible window to orbital angular momentum

How to see the gluons: Deep Inelastic Scattering

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e (1 - \cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

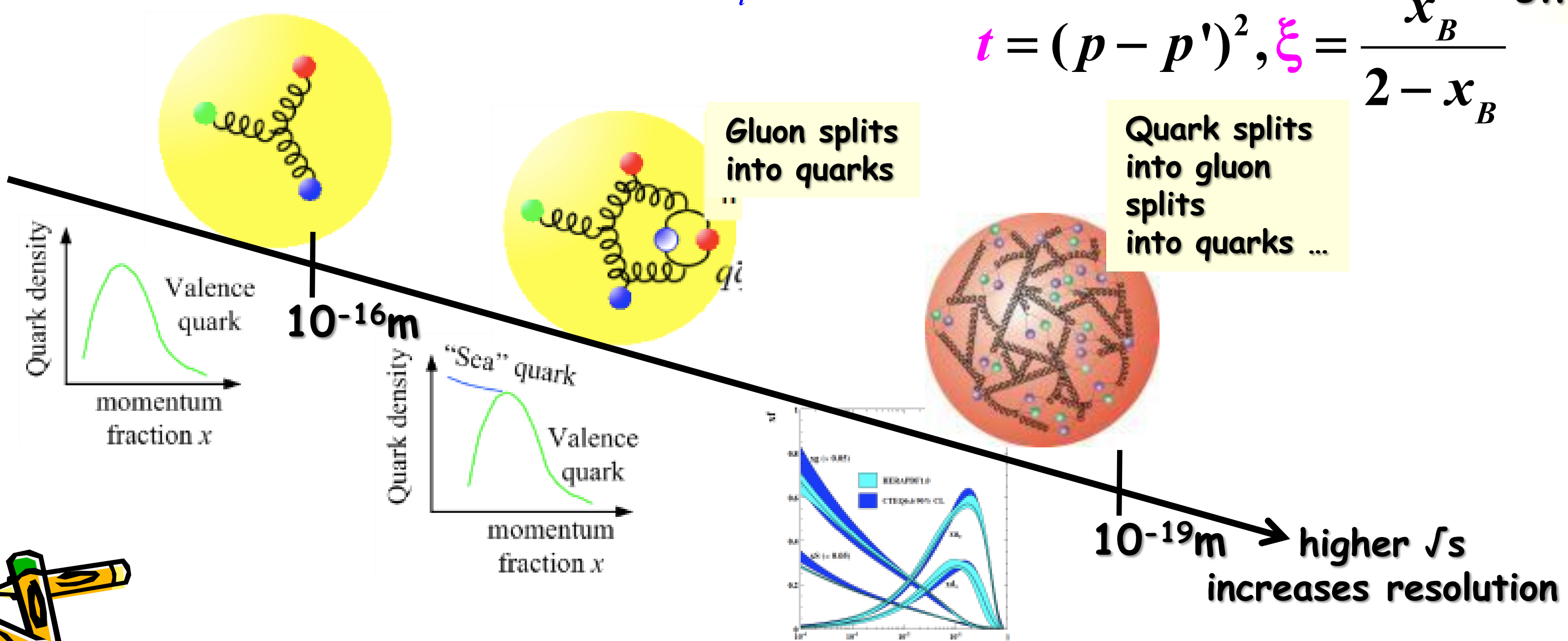
Measure of inelasticity

$$\text{Hadron}: z = \frac{E_h}{\nu}; \qquad x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

p_t^h: with respect to γ^*

$$t = (p - p')^2, \xi = \frac{x_B}{2 - x_B}$$



Our approach to EIC R&D

- Technology choices must be driven by the physics goals.
- Success will be defined by
  - Gathering a community that cross-cuts R&D with physics.
  - Use diverse experience to formulate reasoned plans.
- Well received:
  - *The formation of consortia of universities and national labs … are to be encouraged. In these six proposals we have already seen evidence of such consortia forming around tracking and PID…*
  - *The collaboration emphasized their intention to carry out extensive physics simulations to shape the direction of future detector R&D proposals. … The committee appreciates and encourages this approach. Only after the demanding simulation effort progresses can detector R&D proceed with the desired focus.*
- *Current Focus:*
  - *BUILD THE EIC!*
  - *Do R&D Targeted toward full scale and eventual implementation!*

Today's Presentation:

- Collaboration Status
  - Institutional
  - Individual
- Progress Report on Detector Performance Requirements
  - Momentum Resolution from F_L (semi-analytical)
  - PID purity specifications
- Progress Reports on Hardware Efforts
  - Current Accomplishments (brief)
  - Establishing coherence & community
- Request for funding in these areas:
  - Funding for TPC/HBD Development.
  - Funding for FWD GEM Tracker Development.
  - Funding for FWD "Light Gas" Cherenkov/Mirror Development.
  - Continued Funding for 3-Coordinate readout tests.

Collaboration Status

- A "consortium" of diverse efforts is most effective if all members participate actively and the group builds comradery.
- We have gone through the process of having our member institutions re-affirm their commitment to the group:
  - MIT is a current institution only via Surrow, who will to Temple University
  - Temple University will remain via Surrow.
  - Thomas Jefferson Lab is added via Alexandre Camsonne.

- We continue to expand collaborative efforts:
  - U.Va. and FIT together on forward tracker sector.
  - BNL, Yale, and Stony Brook together on TPC/HBD.
  - Stony Brook, U.Va, and BNL together on Fwd. Cherenkov.
  - BNL, Jefferson Lab together on readout chip development.

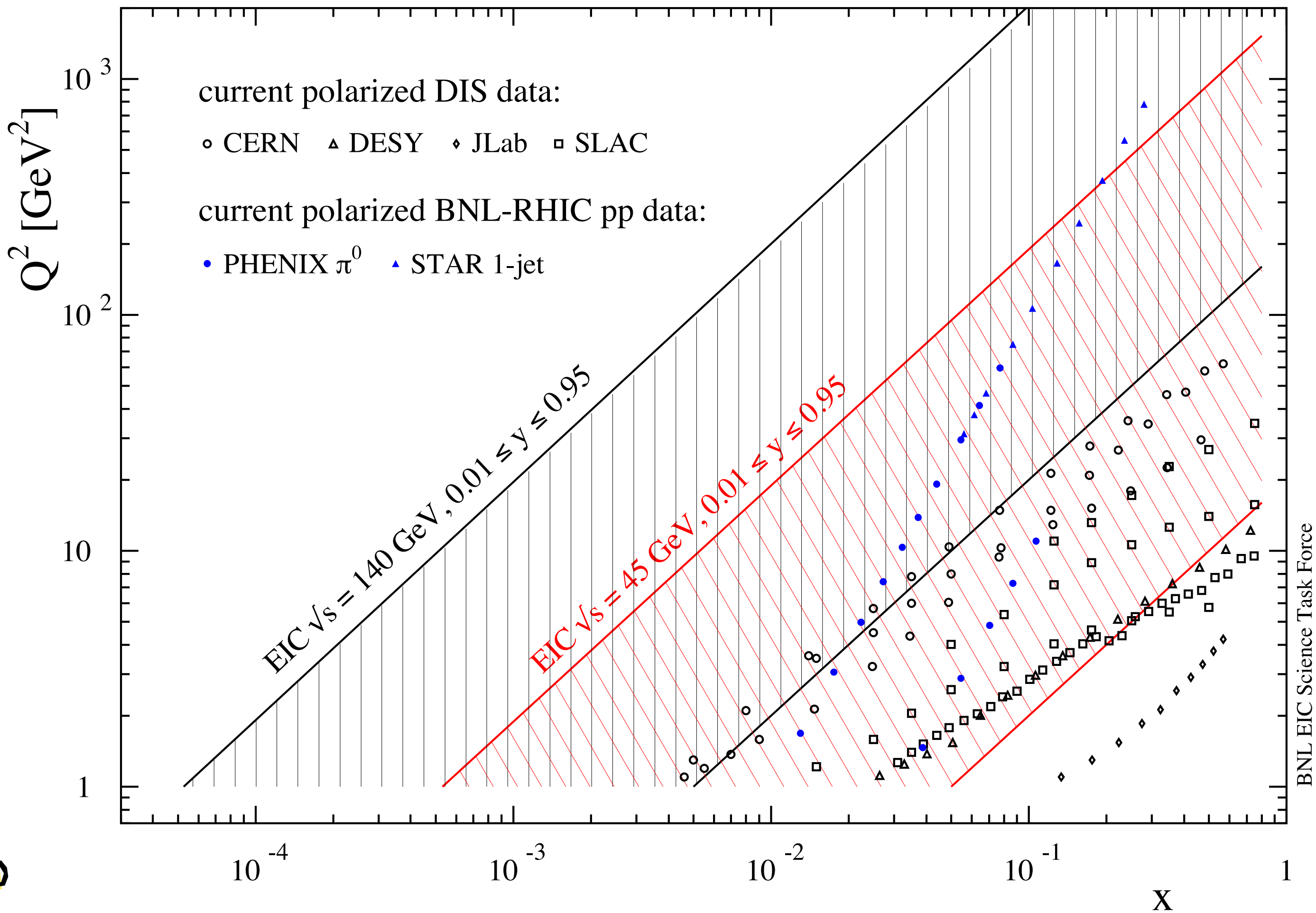
Physics-driven Detector Performance

- "Golden Measurement" is $F_L(x,Q^2)$:
  - Direct access to gluon modifications:
    - $\sigma_{red} = F_2(x,Q^2) - \frac{y^2}{1-(1-y^2)^2} F_L(x,Q^2)$ (here y is INELASTICITY)
  - Demanding upon detector resolution(s)
- This measurement requires that we measure the reduced cross section $\sigma_{red}(x,Q^2)$ at various beam kinematics so as to find the variation over a range in inelasticity (y) and thereby measure F_L
- One can semi-analytically factorize the error in and reduced cross section measurement due to experimental measures.
- Some physics realities (*e.g.* initial state radiation) affect the physics , but are NOT ADDRESSED by detector precision.

x-Q² coverage: for $\sqrt{s} = 45 - 140$ GeV

Wide and continuous coverage in Q^2 at fixed x at all Sqrt(s)

M. Stratmann



The observable for F_L is σ_{red}

- $$\sigma_{red} \equiv \frac{d^2\sigma}{dxdQ^2}\left(\frac{d^2\sigma_{Mott}}{dxdQ^2}\right)^{-1} = \frac{Q^4 x}{2\pi\alpha^2 Y_+}\frac{d^2\sigma}{dxdQ^2}$$
- $$\sigma_{red} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)$$
- **The measurement is made by counting (dN) in bins of some width $\Delta\ln(x)$ by $\Delta\ln(Q^2)$ (squares on log-log)**
- $$d^2N = \mathcal{L}\frac{d^2\sigma}{dxdQ^2}dxdQ^2 =$$
  $$\mathcal{L}\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right)\frac{2\pi\alpha^2 Y_+}{Q^4 x}dxdQ^2 =$$
  $$\mathcal{L}\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right)\frac{2\pi\alpha^2 Y_+}{Q^2}d\ln(x)d\ln(Q^2)$$
- $$\frac{d^2N}{d\ln(x)d\ln(Q^2)} = \mathcal{L}\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right)\frac{2\pi\alpha^2 Y_+}{Q^2}$$

Parameterized: via MRST2002 (NLO)

Simple Kinematics

Errors due to stats & resolution:

- $$\frac{d^2N}{d\ln(x)d\ln(Q^2)} = \mathcal{L}\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right)\frac{2\pi\alpha^2 Y_+}{Q^2} \equiv \mathcal{L}M(x,Q^2) \equiv \mathcal{L}\bar{M}(p,\theta)$$
- **Error Summary:**
  - $$\frac{\delta\left(\frac{d^2N}{d\ln(x)d\ln(Q^2)}\right)}{\frac{d^2N}{d\ln(x)d\ln(Q^2)}} = \frac{\frac{\partial\bar{M}}{\partial p}\delta p}{\bar{M}} \oplus \frac{\frac{\partial\bar{M}}{\partial\theta}\delta\theta}{\bar{M}} \oplus \frac{1}{\sqrt{\mathcal{L}\bar{M}(p,\theta)\Delta\ln(x)\Delta\ln(Q^2)}}$$

We assume that the correction due to detector effects should not exceed 20% in order to achieve better than 1% systematic error

- $$\delta p = \varepsilon\left(\frac{\partial\ln(\bar{M})}{\partial p}\right)^{-1};\ \frac{\delta p}{p} = \varepsilon\frac{1}{p}\left(\frac{\partial\ln(\bar{M})}{\partial p}\right)^{-1}$$
- $$\delta\theta = \varepsilon\left(\frac{\partial\ln(\bar{M})}{\partial\theta}\right)^{-1}$$

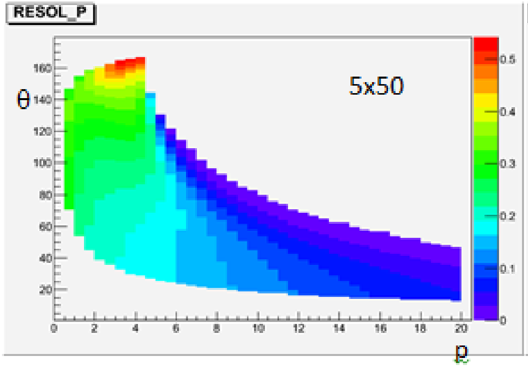
Kinematics & Structure Fcns

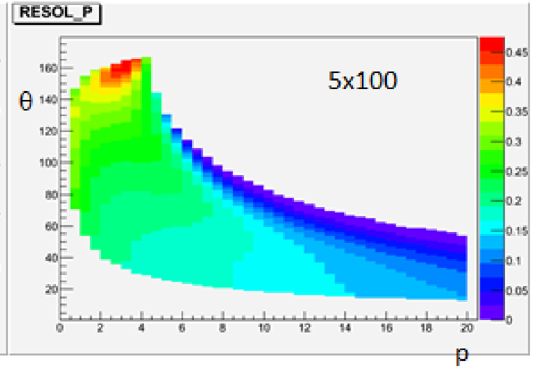
User Input

Detector errors need not be smaller than Statistical.

However, at EIC, the stat errors on σ_{red} are VERY small.

Momentum Resolution Limits





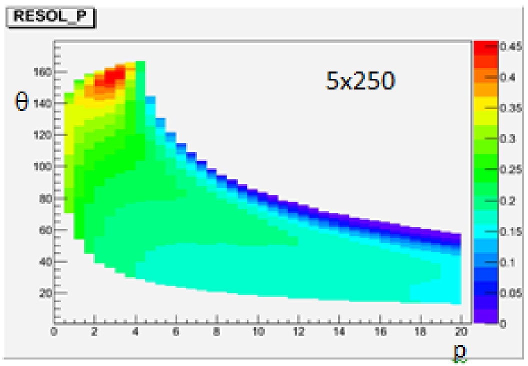
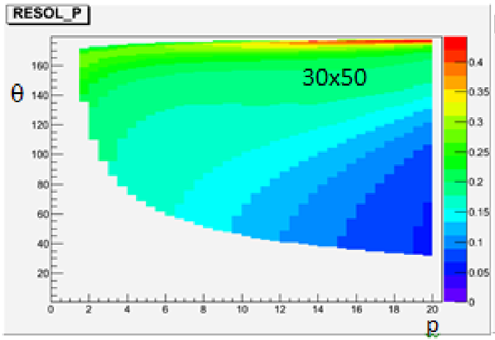
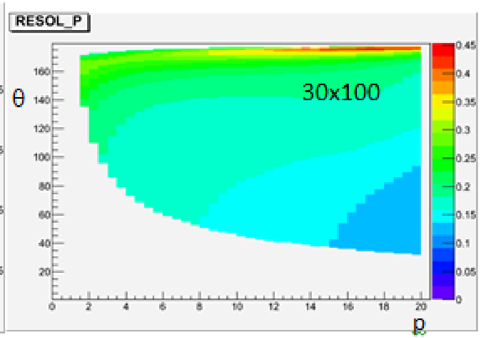


Figure 1: Plots of required momentum resolution as a function of lab angle and momentum. Colors represent δp/p

- Requirements vary strongly with beam energy.





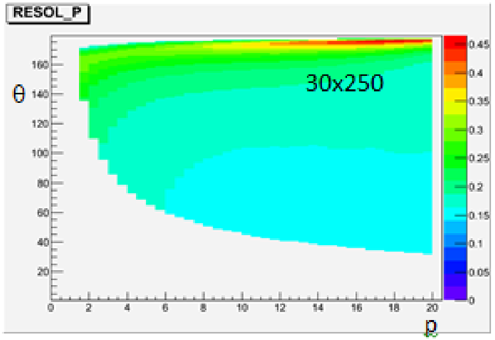
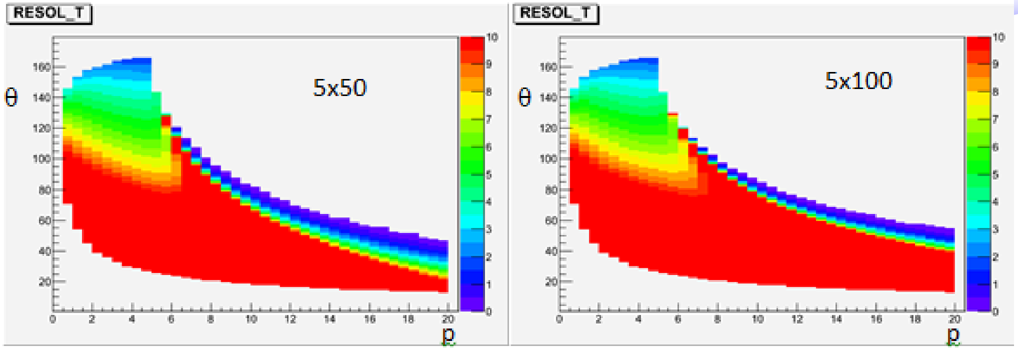
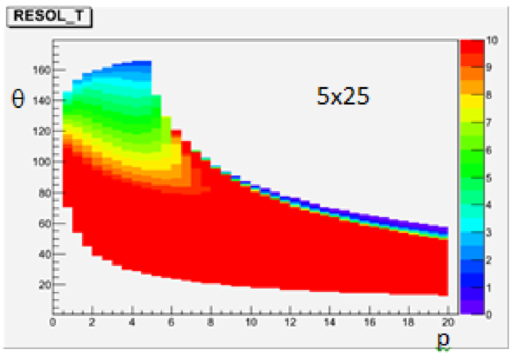


Figure 3: Plots of required momentum resolution as a function of lab angle and momentum. Colors represent δp/p

- Resolution specification requires contributions from both tracking and calorimetry.

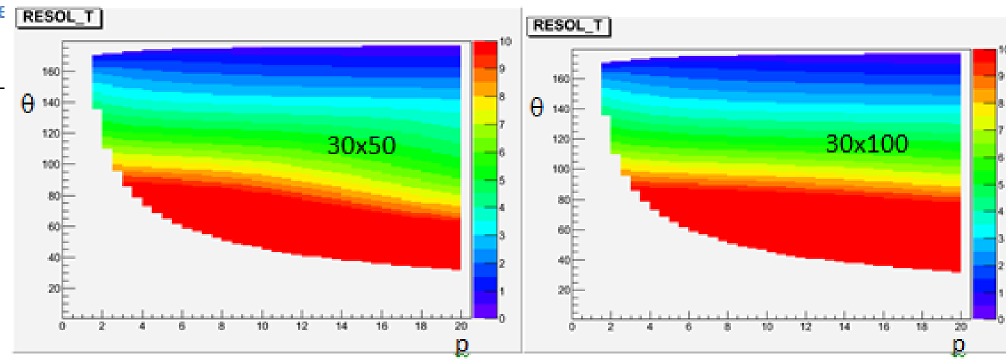
Angular Resolution Limits





- Angular resolution specified in degrees.

Figure 2: Plots of required angular resolution as a function of lab angle and momentum. Colors represent δθ in degre



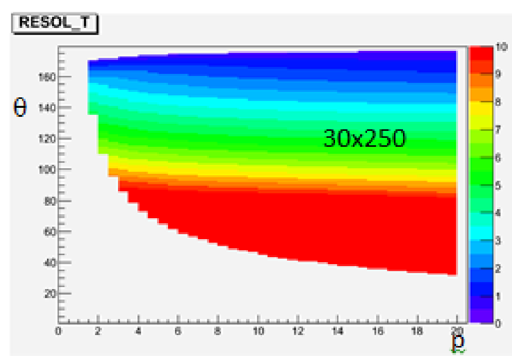
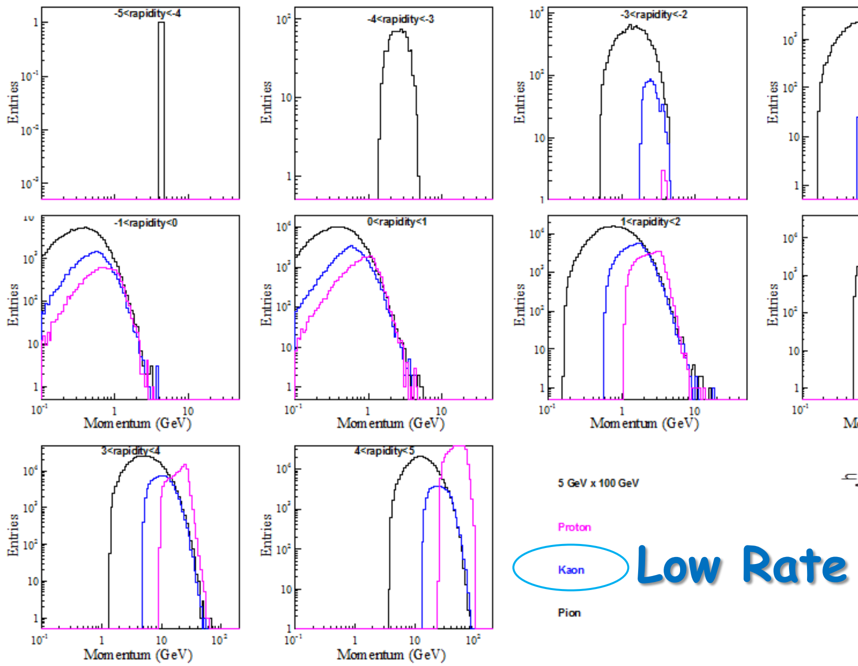


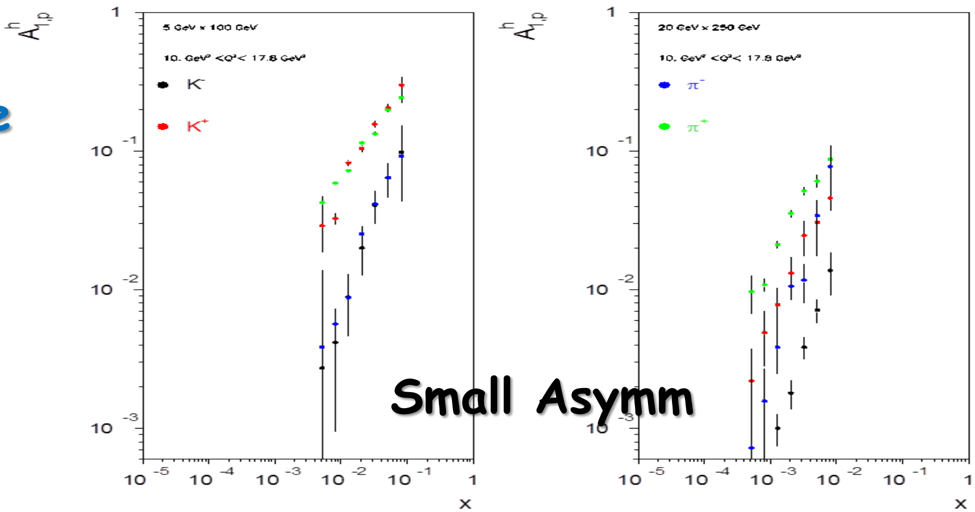
Figure 4: Plots of required angular resolution as a function of lab angle and momentum. Colors represent [illegible] in degrees.

- These plots are useful to entire EIC community as physics-driven limits on detector perf.

Particle ID Constraints.

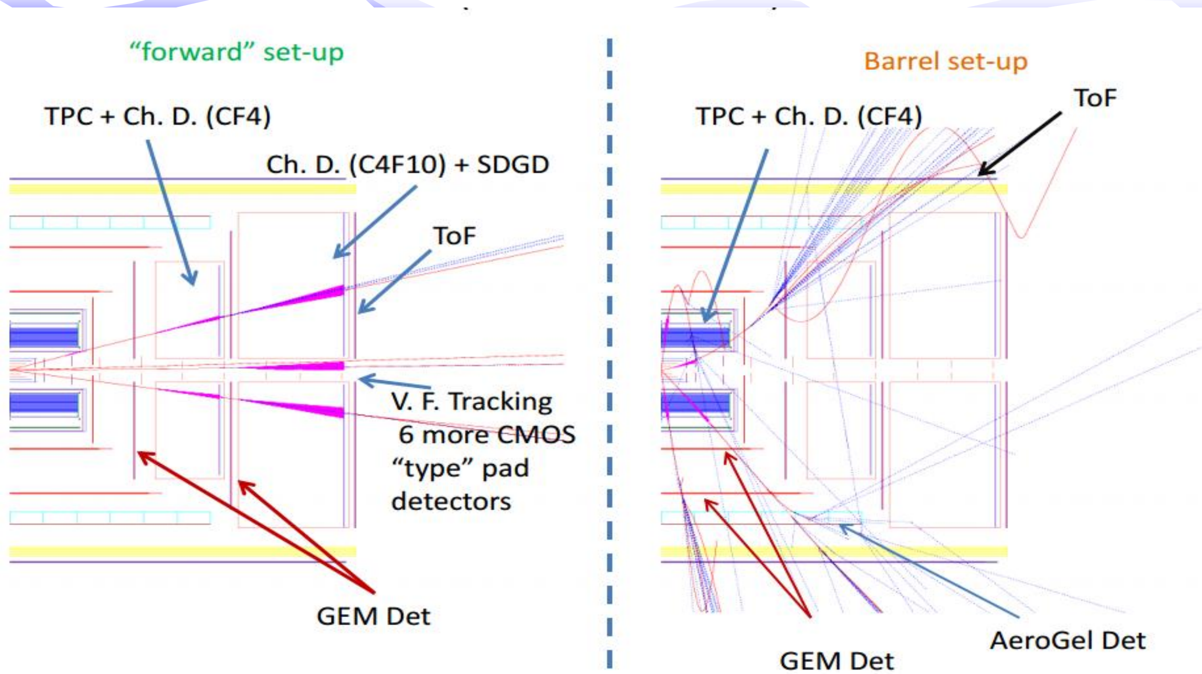


- Particle Identification limit driven by asymmetry of K-
  - $\bar{u}s$ there small spin asymm. compared to pions.
  - Less abundant than pi.



- REQUIRE 95% purity of K- Sample.
- REQUIRE <u>positive</u> Kaon ID.

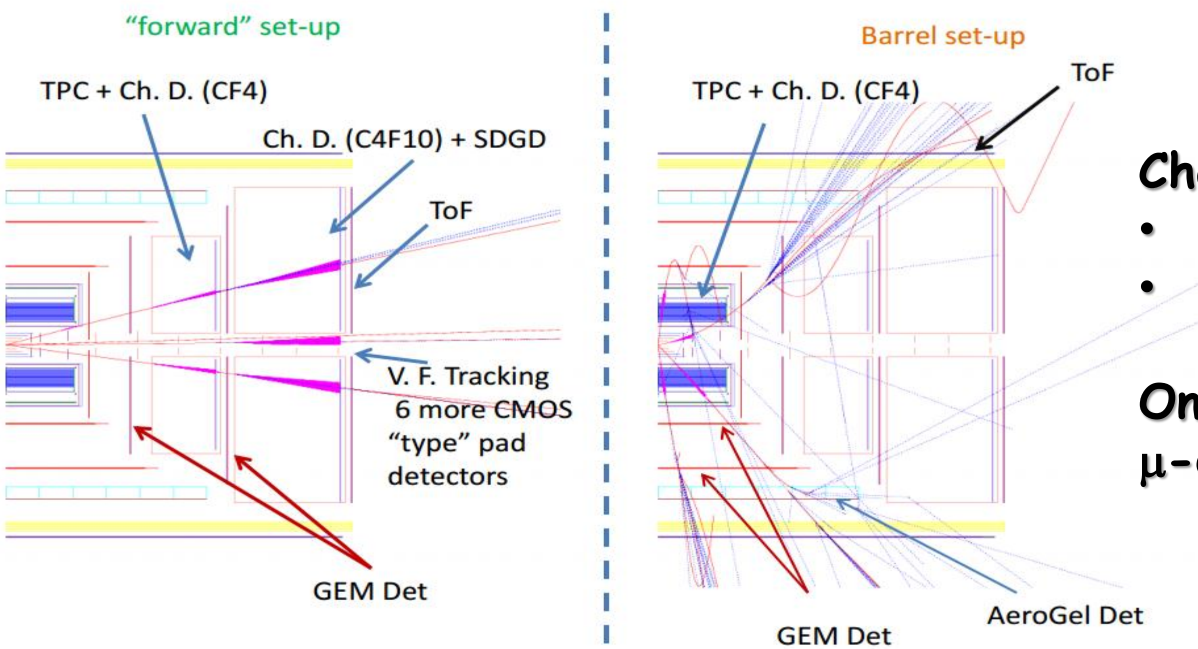
Detector Design(s) for R&D



- Central Barrel:
  - MAPS silicon for vertex.
  - TPC/HBD provides low mass, good momentum, dE/dx, eID.
  - "fast layer" desired since both TPC and MAPS integrate hits over multiple crossings.
  - Additional PID from
    - Proximity RICH –or– DIRC –or– psec TOF

RED indicates presently proposed R&D

Detector Design(s) for R&D



Challenges in FWD GEMS:
- Size of GEM Area.
- μ-drift readout.

Once GEM Area is solved, μ-drift via gaps & Electr.

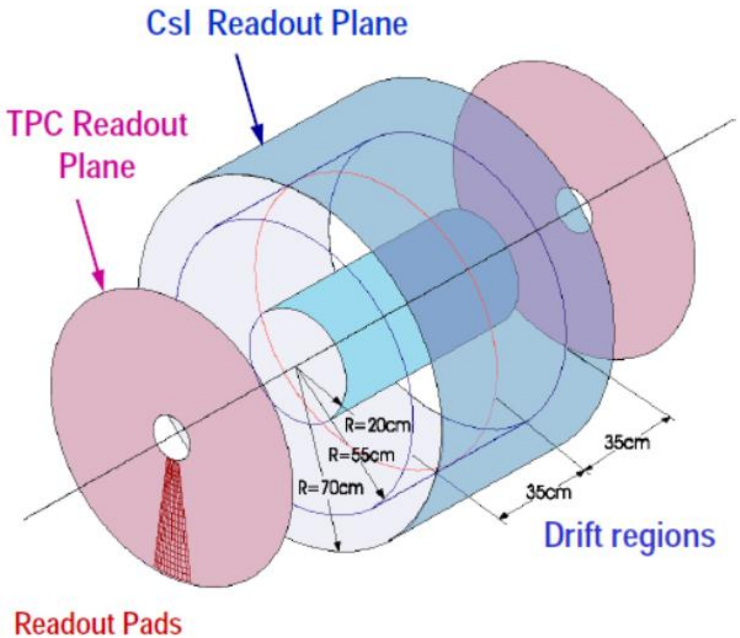
- Forward:
  - MAGNETIC FIELD SHAPE (collab. with Brett Parker).
  - MAPS silicon for very small angles.
  - Planar GEM Detectors (μ-drift?) for p at intermediate angles.
  - "Heavy Gas" RICH for PID at lower momenta.
  - Light Gas RICH (CF_4) for PID at highest momenta.

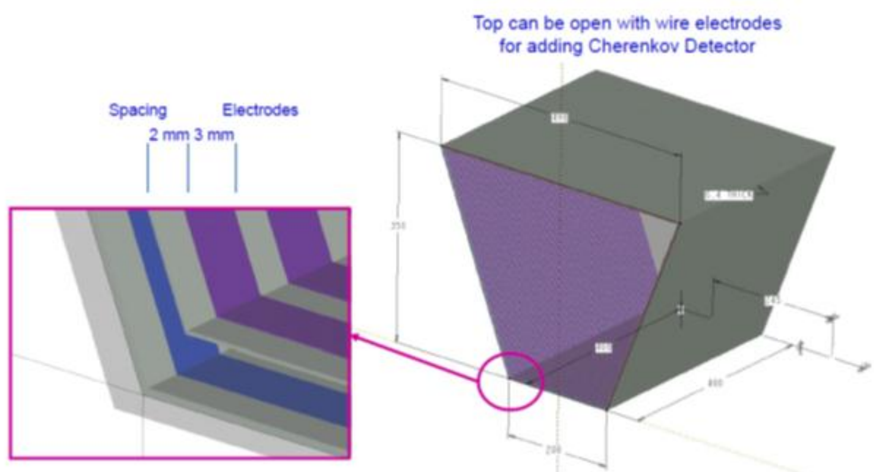
RED indicates proposed R&D

BLUE indicates R&D w/o Funding

TPC with HBD outer readout.

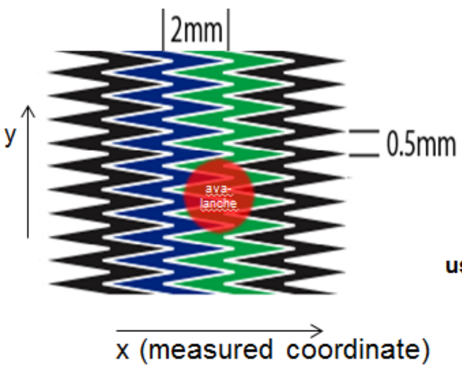
- Use CF_4 mixture to provide fast drift TPC.
- Design field cage to allow Cherenkov light through
- Cherenkov "stripe" detected (mag deflection).
- Natural follow-on to prior research of BNL, Yale, SBU.
- Provides broad spectrum PID.



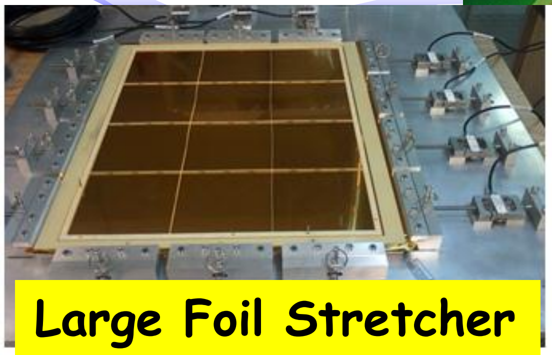


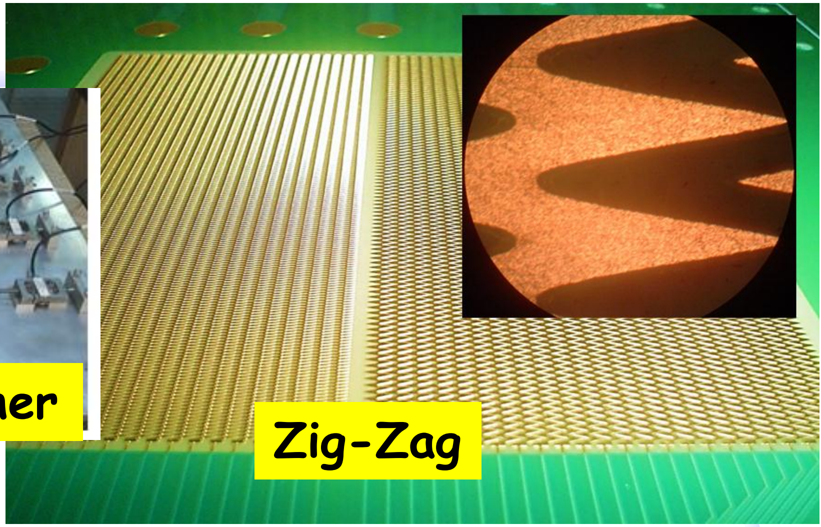
- **Goals:**
  - Develop smaller TPC – yr1
  - Develop full sector – yr2

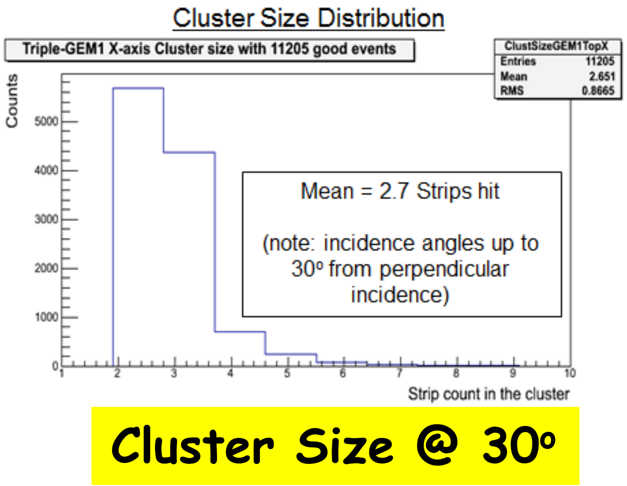
Planar GEM Sector Test

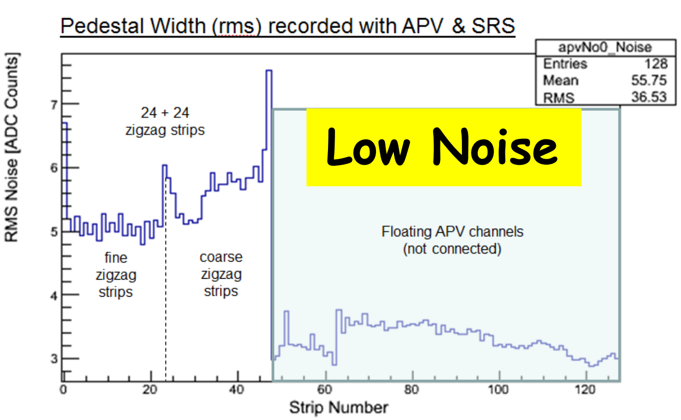


Sample of 11k pulses using cosmics





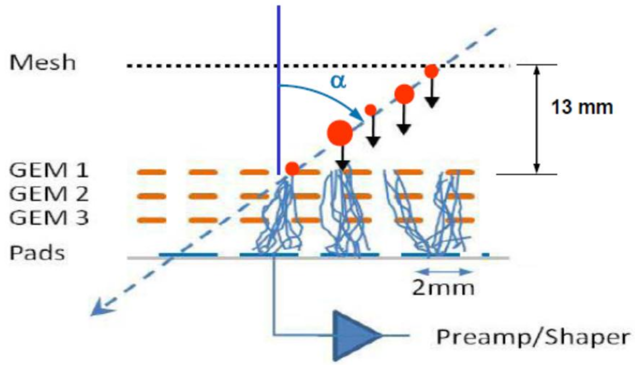


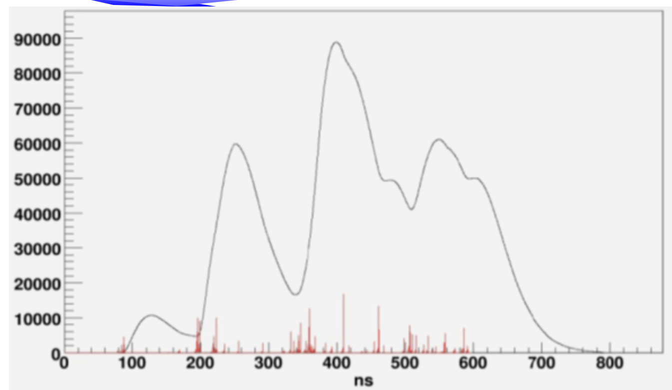


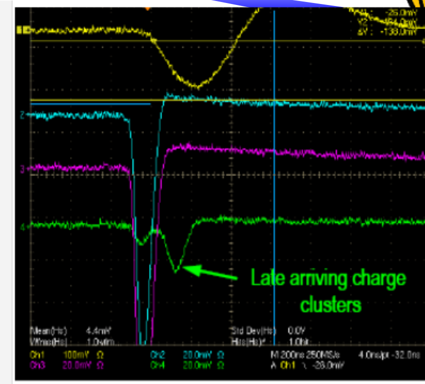
- Need to address channel count to contain costs (Zig-Zag).
- Need to manufacture to scale.
- Fits current UVa and FIT developments.

- **Goal:**
  - Develop and test full sector over two years

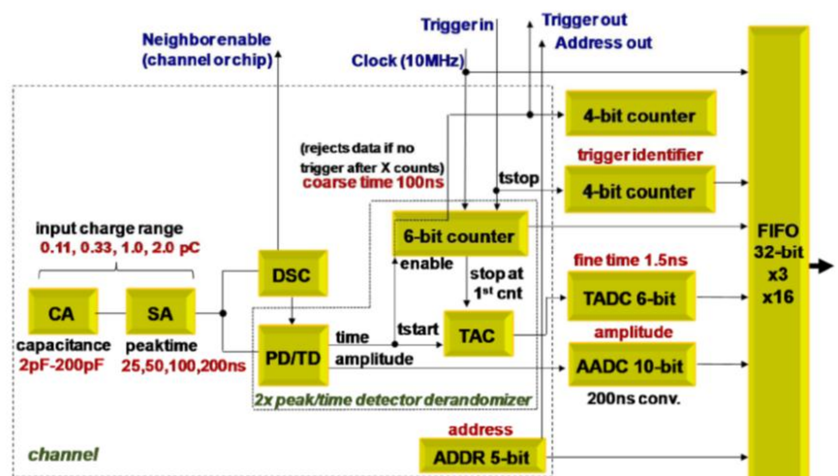
GEM with μ-drift





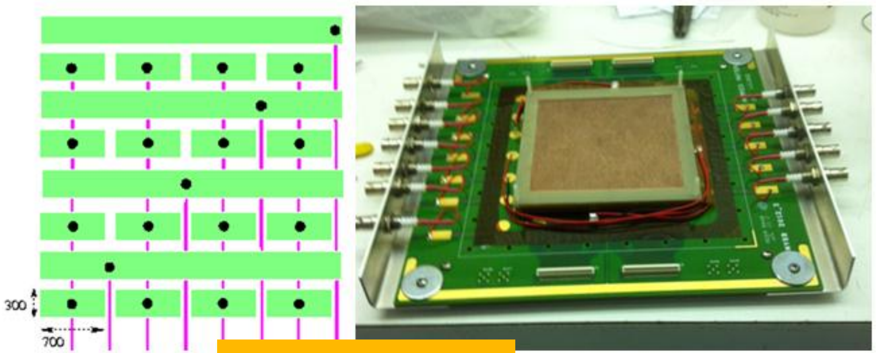


- ❑ Planar GEM detectors could be developed for "cluster-counting" mode.
- ❑ Our measurements show promising capabilities.
- ❑ ATLAS chip development (so far) compatible with EIC needs.

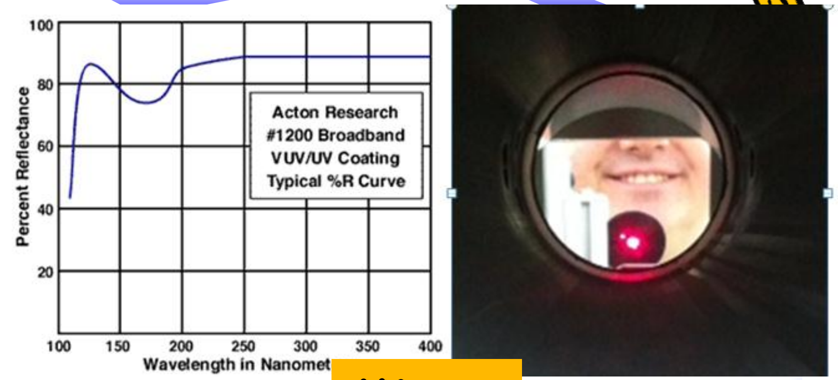


Simple upgrade to functional GEM sector via:
- Increased mesh-GEM gap (few cm)
- Appropriate Electronics w/ moderate res timing.

Light Forward Cherenkov Detector

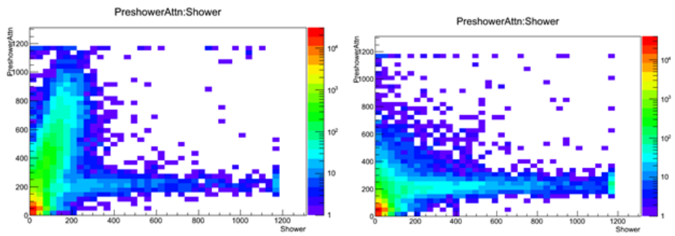


Focal Plane



Mirror

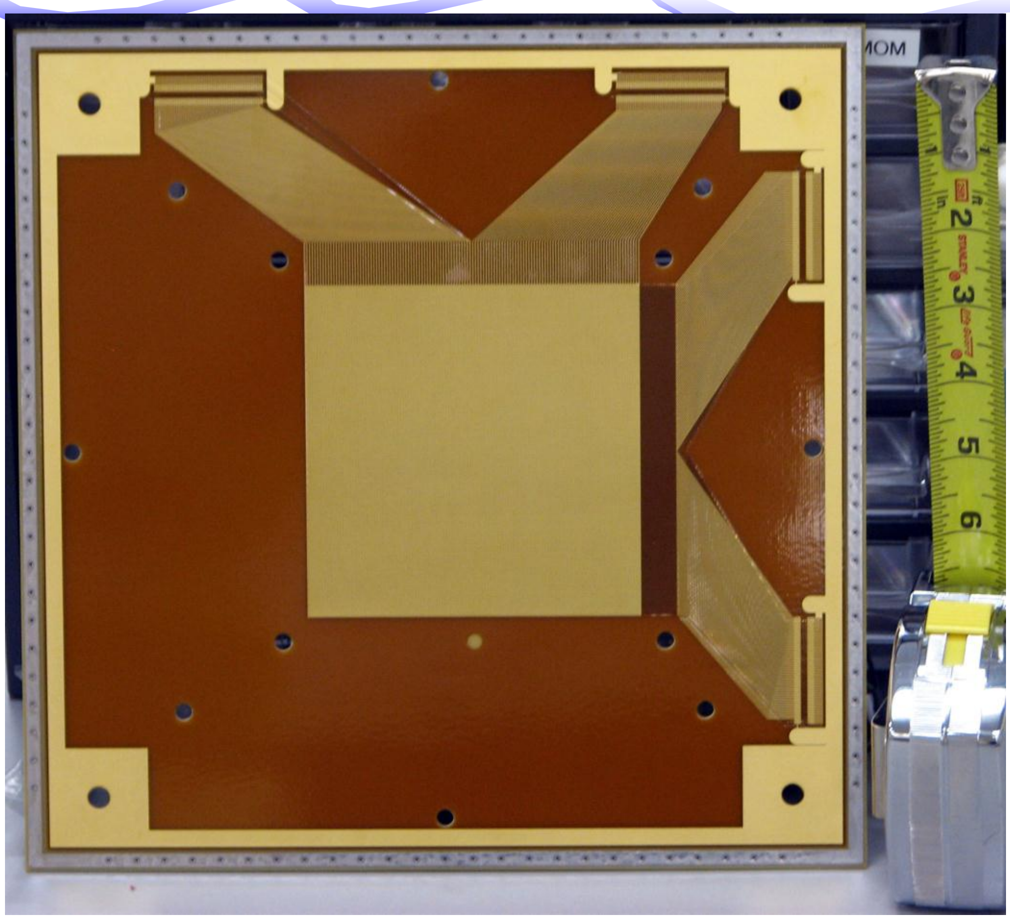
Test Beam (ongoing)

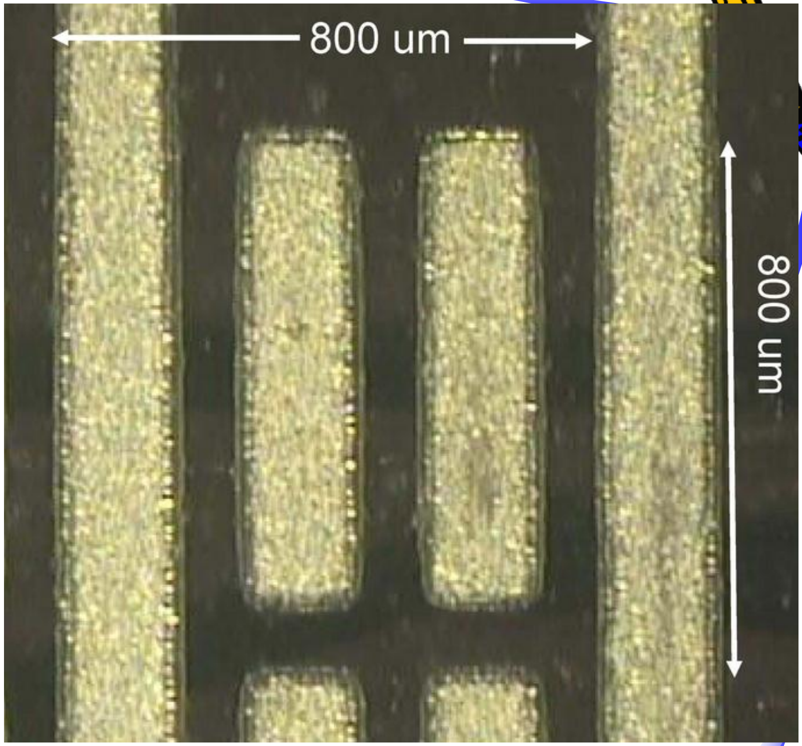


Electrons Rare…

- Goal:
  - Further running of prototype.
  - Develop LARGE UV Mirrors

3-Coordinate Readout

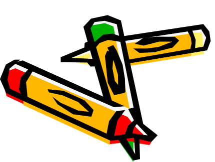




- Production is successful on 3-Coordinate Readout.
- Requesting funds for test beam.

Budget

- Budget includes "shared" PostDoc
- FIT rates are used to minimize cost.
- Postdoc travel:
  - FIT
  - UVa
  - Long Island
- Two current applicants for position who have indicated they would accept.



Item	Year 1	Year 2
Combined TPC/RICH, and Micro-Drift		
Short drift planar prototype detectors	$10,000.00	
Compact TPC prototype	$15,000.00	$10,000.00
CsI Cherenkov detector		$15,000.00
Cosmic ray test stand	$15,000.00	
Gas, supplies, etc	$10,000.00	$10,000.00
Test beam activities		$15,000.00
Technical support, designer	$10,000.00	$15,000.00
Subtotal (incl. 50% overhead)	**$90,000.00**	**$97,500.00**
Forward Tracking		
3 large-area prototype GEM detectors	$10,000.00	$20,000.00
Zigzag and strip-pad r/o boards (design & construction)	$10,000.00	$10,000.00
mechanical stretcher for large foils	$12,000.00	$0.00
GEM frames w/ various spacers for stretcher tests	$3,000.00	$0.00
SRS electronics	$0.00	$20,000.00
Materials & Supplies (gas, cables, …)	$3,000.00	$3,000.00
Equipment & Material Subtotal (incl overhead)	**$38,750.00**	**$53,750.00**
Cherenkov		
Test Beam Expenses	$12,500.00	$10,000.00
CF4 and ArCO2 gas	$2,800.00	$5,000.00
Clean Room Supplies	$2,500.00	$2,500.00
Small mirror substrates	$2,000.00	$0.00
Refurbish transparency mon. for reflectivity measurement	$3,000.00	$0.00
Small evaporator materials & supplies	$3,000.00	$0.00
Large evaporator refurbishing	$5,000.00	$32,000.00
Thin substrate development	$4,000.00	$18,000.00
Subtotal (incl 48% on-campus overhead)	**$51,504.00**	**$99,900.00**

Budget continued.

Equipment Subtotal	**$180,254.00**	**$251,150.00**
Domestic: Joint work at FIT, UVA	$10,000.00	$4,000.00
Foreign: Beam tests, QA at CERN	$10,000.00	$10,000.00
Travel Subtotal (incl overhead)	**$30,800.00**	**$21,560.00**
3 Coordinate Test Beam Effort		
Travel & Housing	$2,000.00	$4,000.00
Supplies, mounts and fixturing		$5,000.00
Subtotal (incl. 26% Yale off campus rate)	**$2,520.00**	**$11,340.00**
Costs Spanning Multiple Tasks		
12 mos. Postdoc (fully loaded)	$85,635.55	$88,204.62
Engineering support	$15,000.00	$15,000.00
Undergraduate student support	$5,000.00	$5,000.00
Postdoc support while on travel	$10,000.00	$15,000.00
Electronics Development	$10,000.00	$10,000.00
Other Common Costs	$5,000.00	$5,000.00
Personnel Subtotal	**$143,335.55**	**$153,404.62**
TOTAL	**$356,910**	**$437,455**

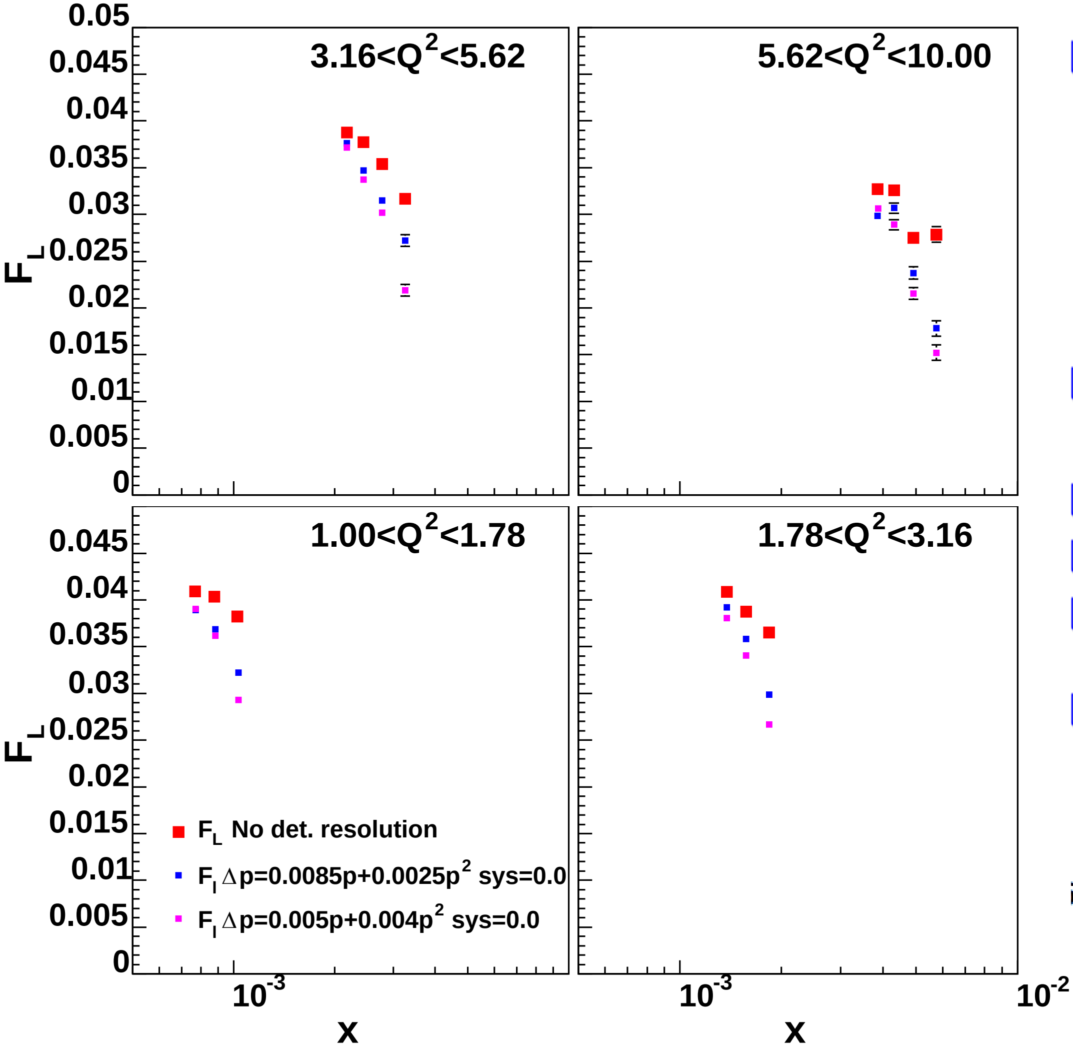
Summary

- We mapped the basic performance requirements for EIC.
- We have defined a targeted research program of three major initiatives:
  - MAGNET Research (initiated within our group, no funds).
  - Central Arm TPC/HBD.
  - Forward Planar GEM Trackers.
  - Forward "light gas" Cherenkov.
- These detector systems meet the requirements.
- These are not inclusive!
  - DIRC, MAPS, "heavy" Cherenkov, proximity Cherenkov, EMC.

- Our goal is to build EIC and so our research is targeted at specific full-sized implementations in the next two years.

BACKUP SLIDES

Why $F_L(x,Q^2)$ is so demanding

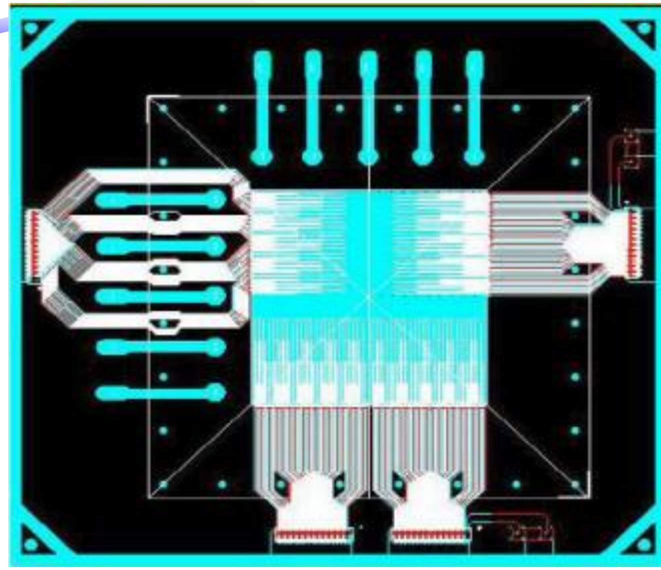


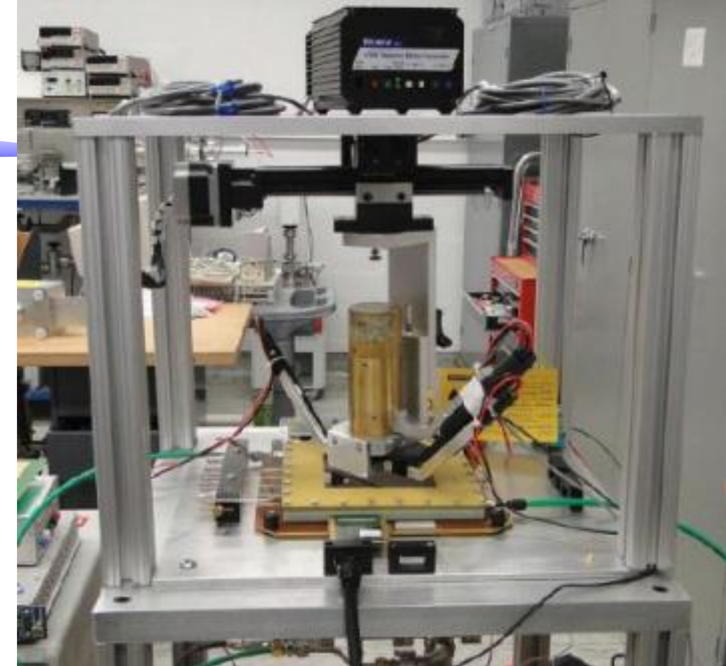
- Reduced Cross Section measured in a single (x,Q^2) bin as function of $\frac{y^2}{1-(1-y)^2} = \frac{y^2}{Y_+}$
  - Intercept measures F_2
  - Slope measures F_L
- Simple detector simulation:

- Errors on σ_{red} are ~1%
- Very little effect on F_2
- Significant effect on F_L

- Desire theoretical guidance on saturation effect on F_L
  - If wishes were fishes…

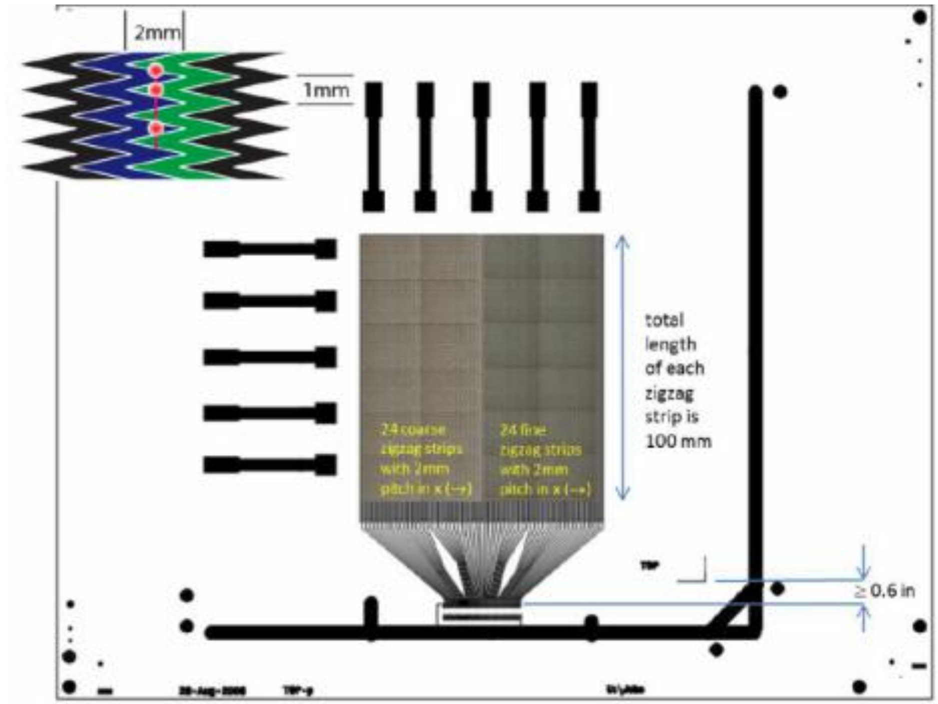
Micro-TPC





- Tests of 1-2cm drift micro-TPC soon coupled to ATLAS chip.
  - 64 ch ASIC (front end only) available Spring 2012.
  - Designing coupling to SRS.
- ^{90}Sr vectored source with 10 micron scan steps.
- CERN "Compass" readout; 2000 channels SRS.
- Alternative readout planes from SBU engineer.
- Several chip options will be identified by proposal time.

Zig-Zag readouts to Reduce Channel Count

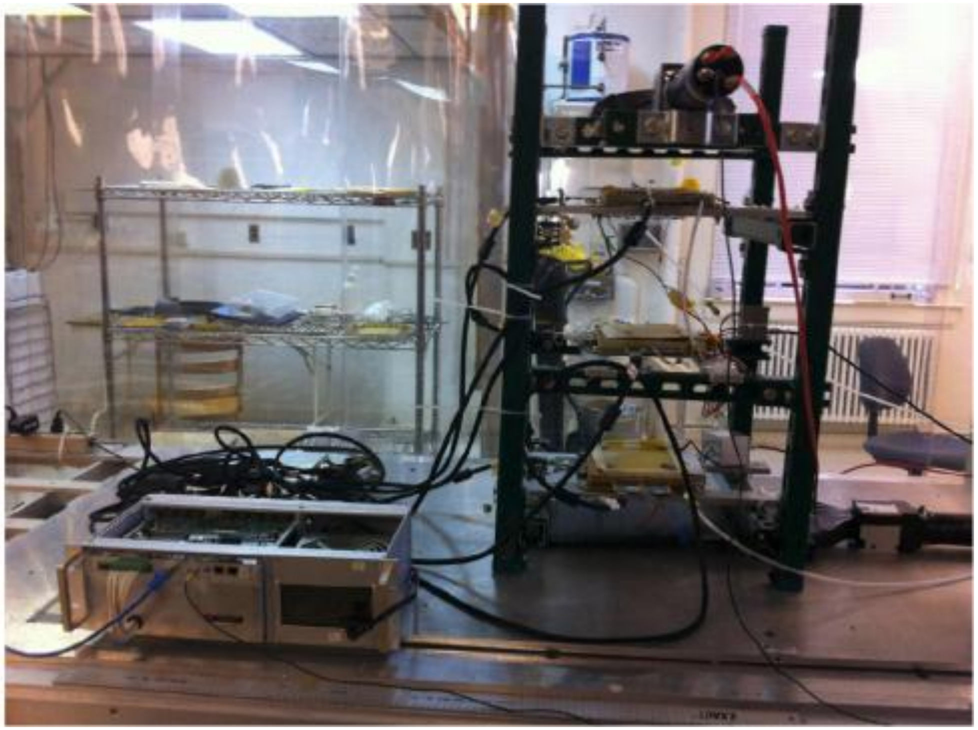


Readout test board compatable with CERN 10x10cm^2 GEMS.

FIT design/
SBU layout

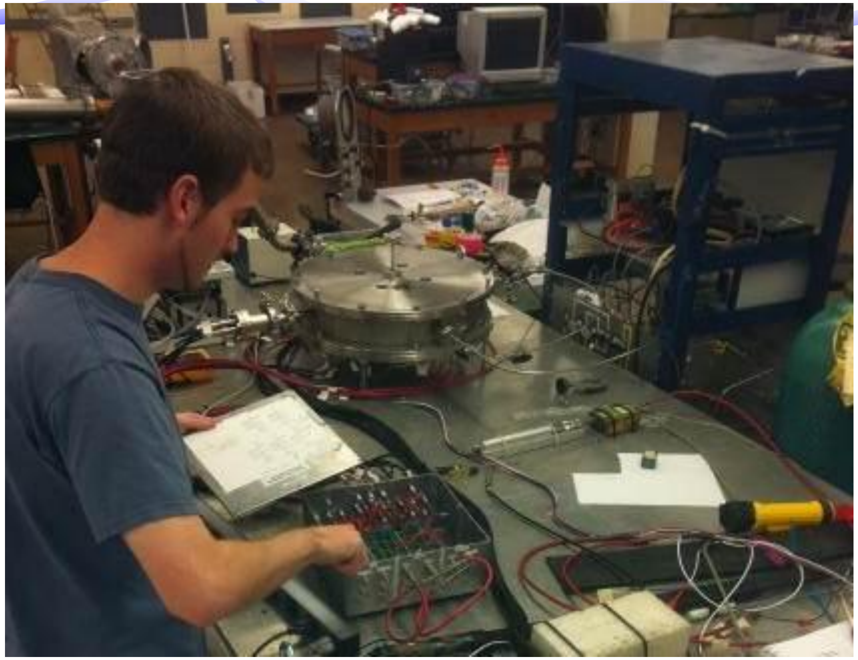
- Investigation of long "Zig-Zag" patterns at FIT.
- Low channel-count readout for very large area GEMs.
- FIT has ~1m-long functioning GEMs as prototypes from CMS.

Dead Area at GEM Edges Reduction



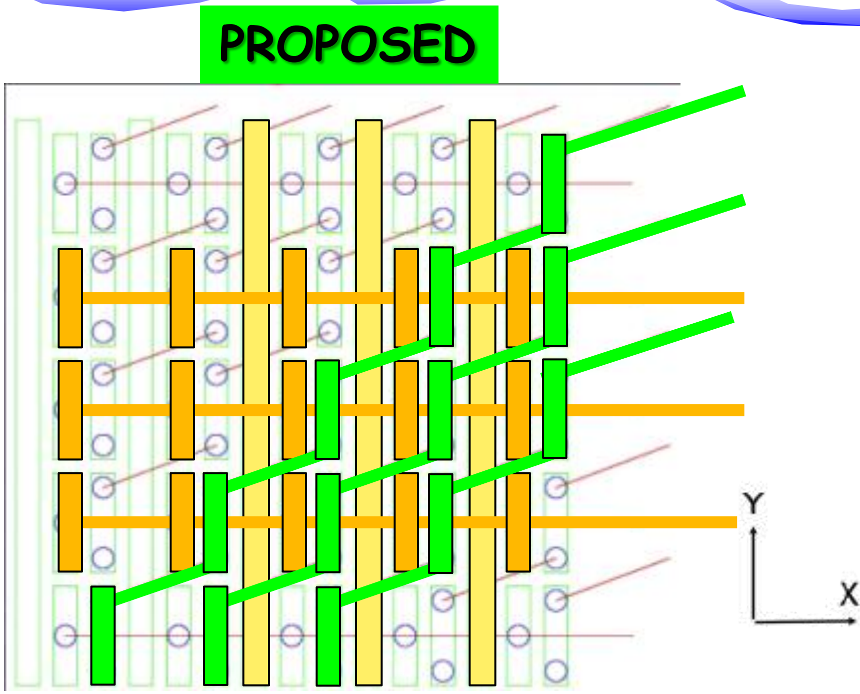
- 2000 channels of SRS running successfully.
- Orders out for 40x50cm^2; Design underway for 90x40cm^2
- UVa will provide tracking & DAQ for RICH Tests @ J-Lab (Spring 2012)

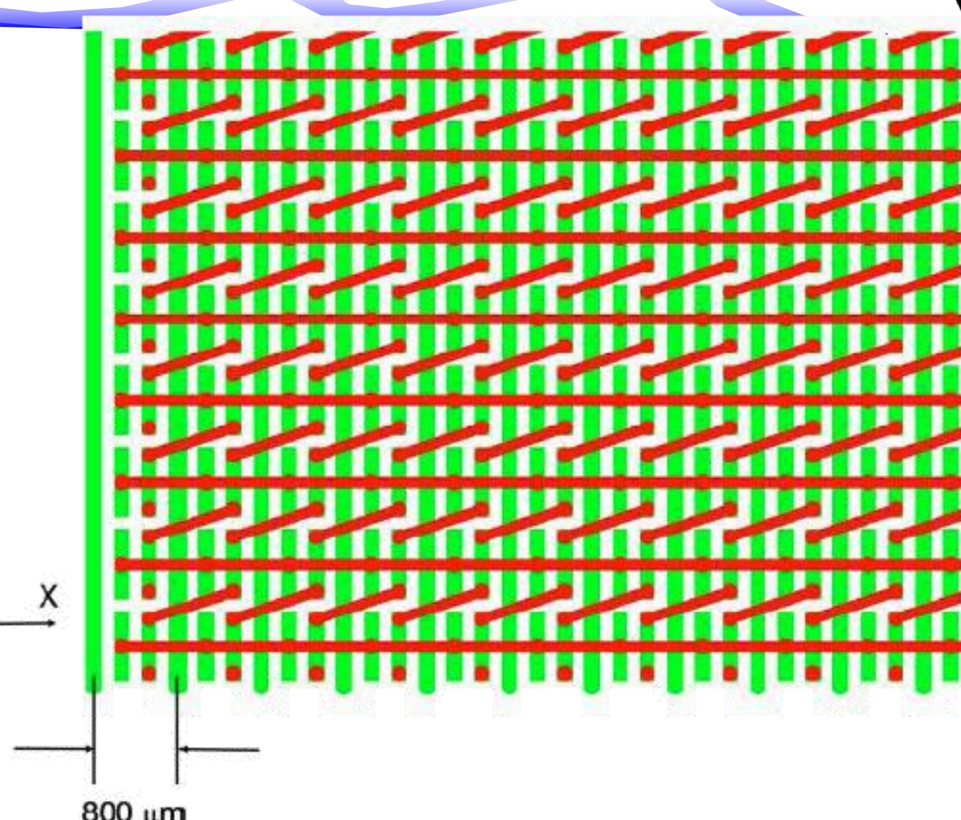
RICH Detector Development



- Test "beam" available in Hall A.
- Joined with Temple & U.Va for two-stage tests:
  - Simple background studies (leave for J-Lab this week!)
  - RICH tests with tracking support in Spring 2012.
- Full-time grad students: Thomas Videbaek, Serpil Yalcin.
  Part-time grad students: Ciprian Gal, Paul Kline, Huijun Ge
- Five undergrads working part-time.

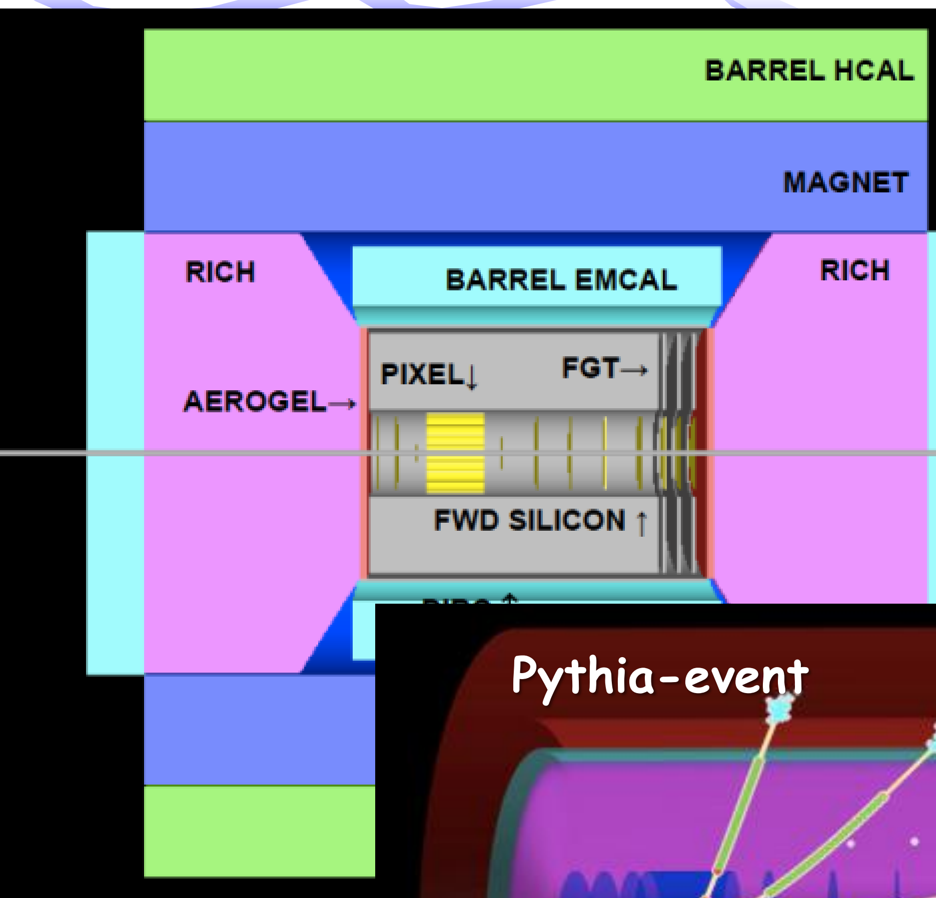
3D Strip-pad Readout Scheme

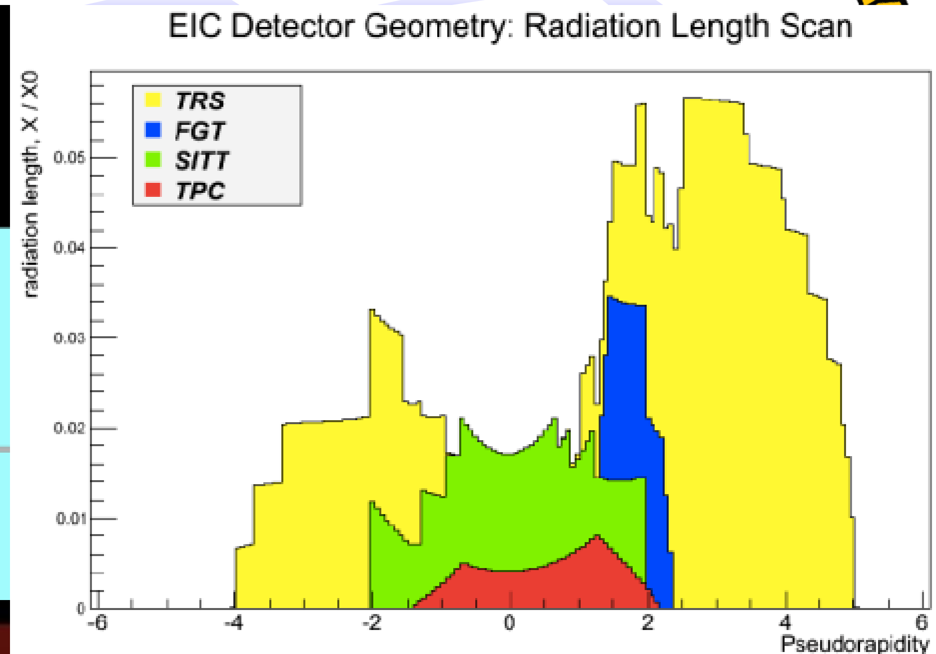


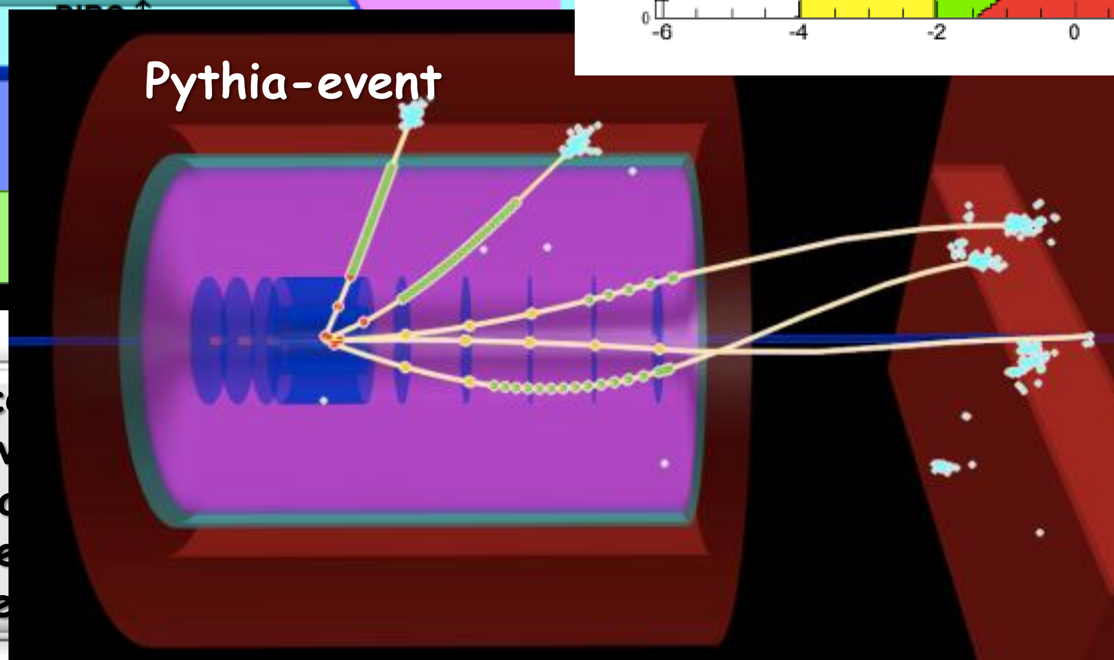


- Layout completed for 880 mm pitch.
- Next is 600 mm pitch (limit of Tech-Etch capability?).
- Beam test 2012.
- BNL and SBU doing detailed simulations of charge deposition and pattern recognition respectively.

Emerging Detector Concept

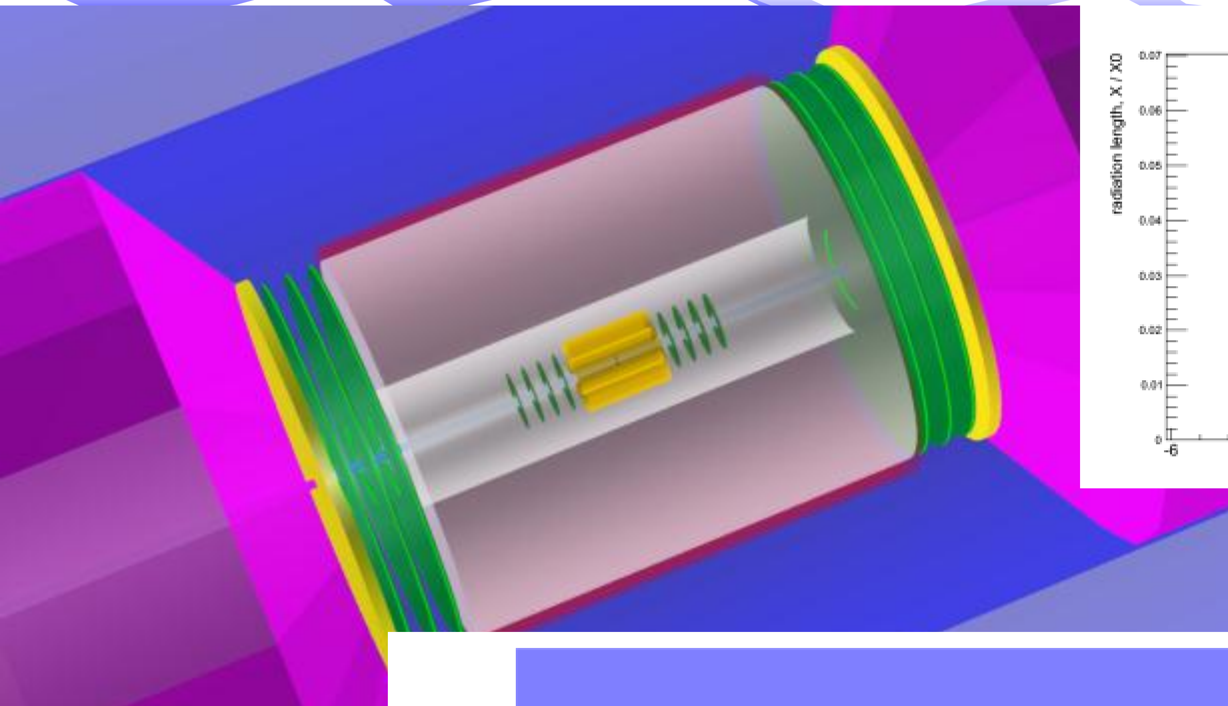


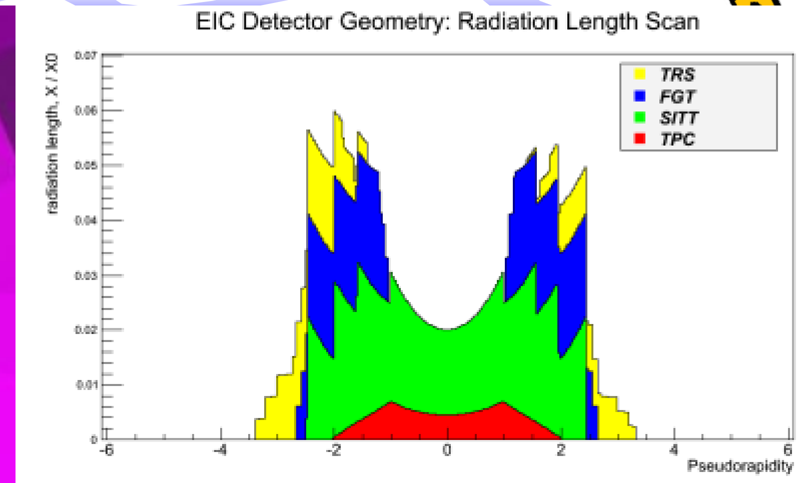


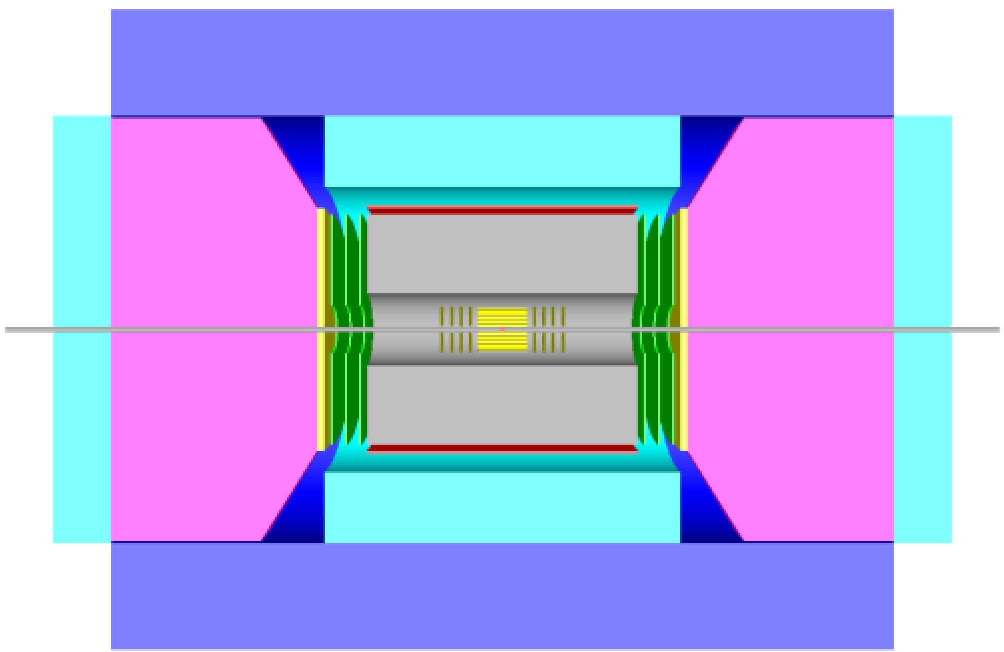


high acceptanc
good PID and v
tracking and c ... lution, lepton PID
low material de ... ung
very forward e

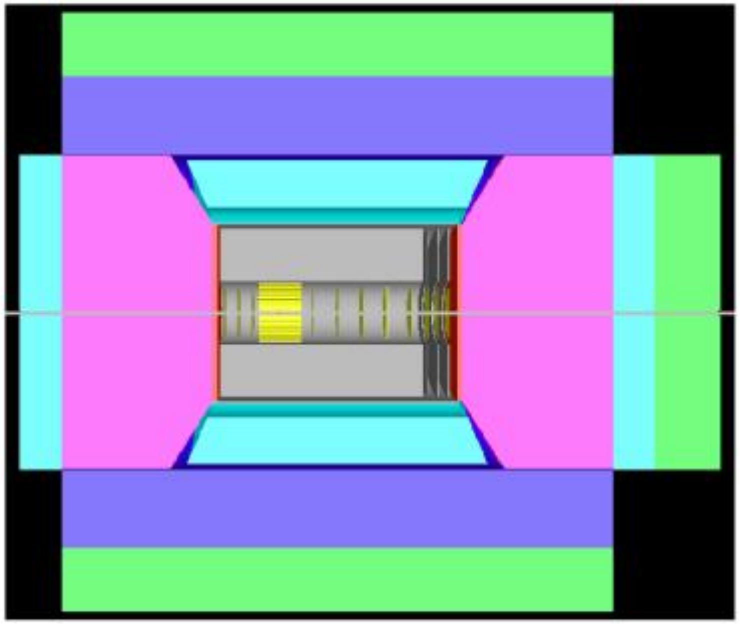
And in a symmetric version…

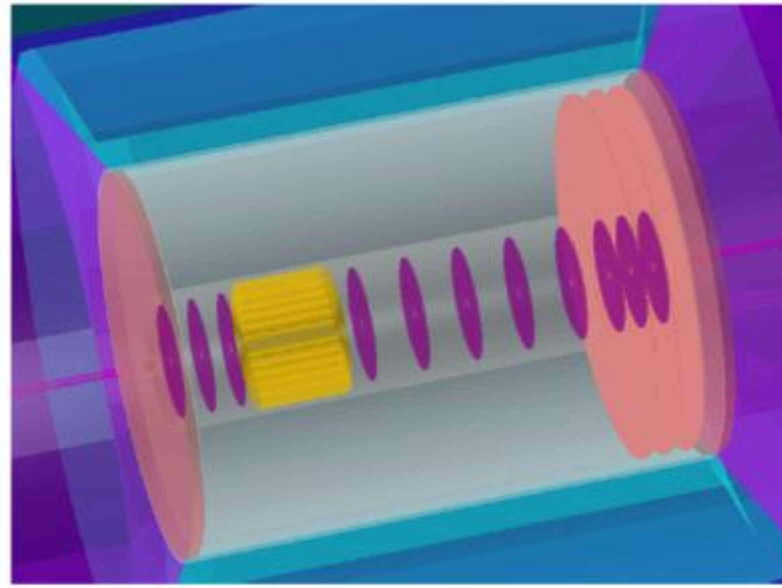






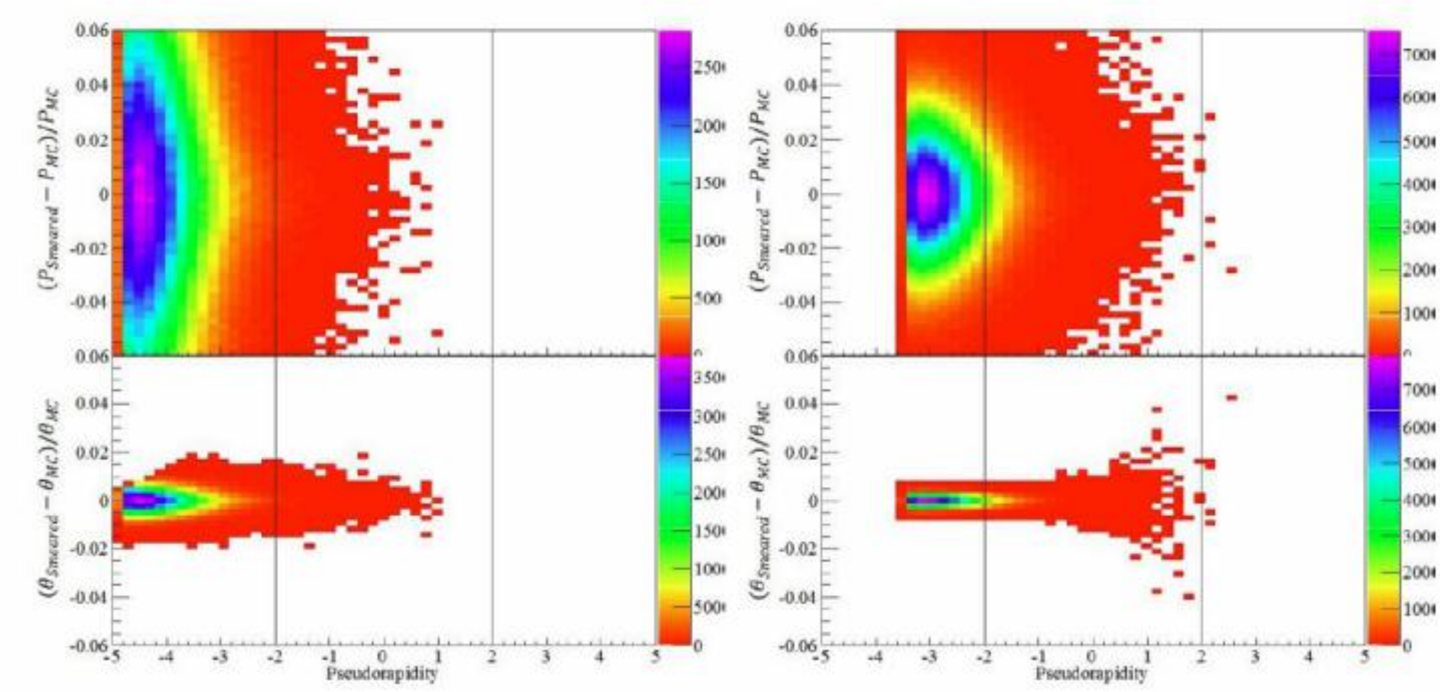
Framework 1: FairROOT





- IO Manager based on ROOT TFolder and TTree (TChain);
- Geometry Readers: ASCII, ROOT, CAD2ROOT;
- Radiation length manager;
- Generic track propagation based on Geane;
- Generic event display based on EVE and Geane;
- Fast simulation base services based on VMC and ROOT TTasks;
- a unified interface to integrate different Monte Carlo (MC) generators
- CUDA support

Framework 2: Smear

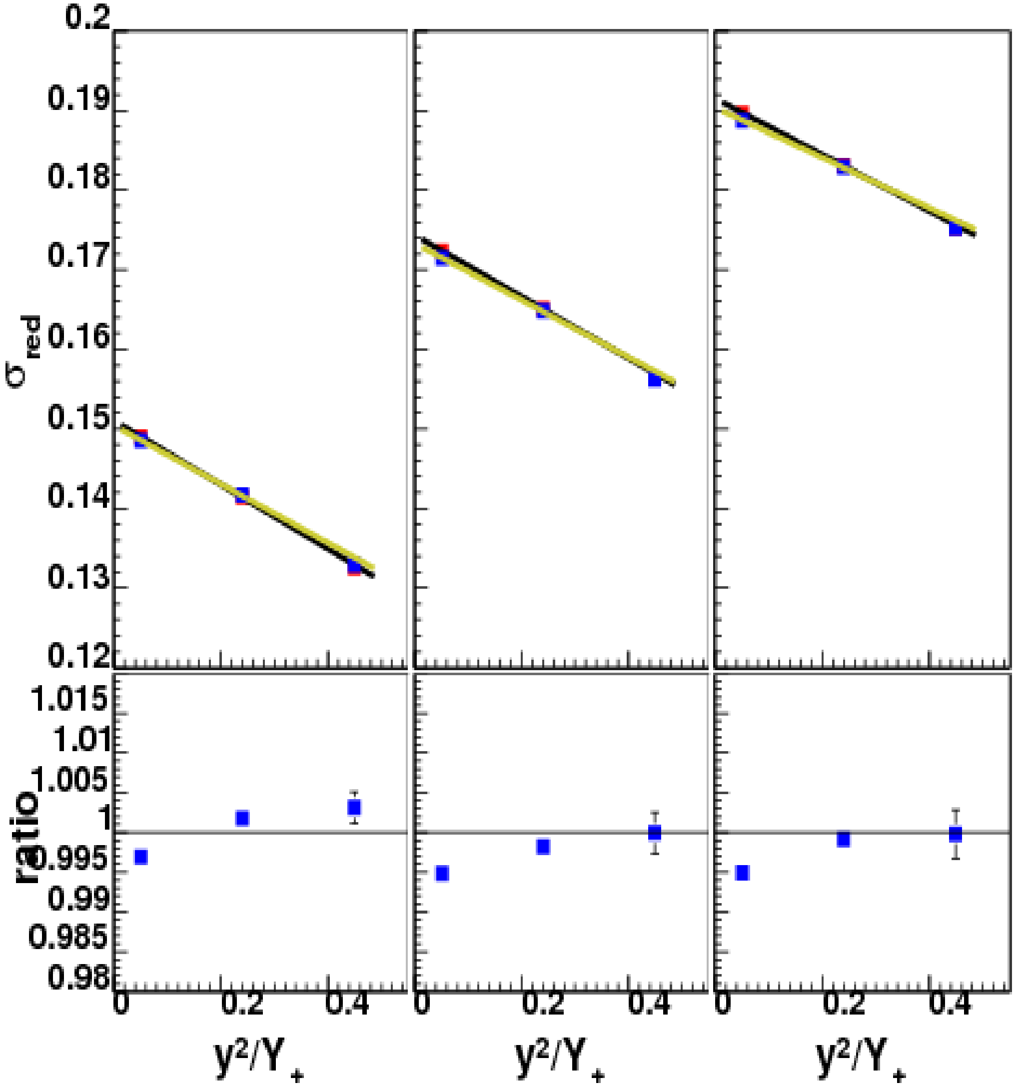


- Layers of "Logical" detectors with smearing function.
- Mis-ID matrix ala HERMES
- Crystal Ball function for Bremsstrahlung tails.

$$\frac{\delta p}{p} = \frac{1}{0.3\,B}\frac{0.0136z}{L\beta cos^2\gamma}\sqrt{n_{r.l.}} + \frac{p}{0.3B}\,\frac{\sigma_{r\varphi}}{L`^2}\,\sqrt{\frac{720}{n+4}}$$

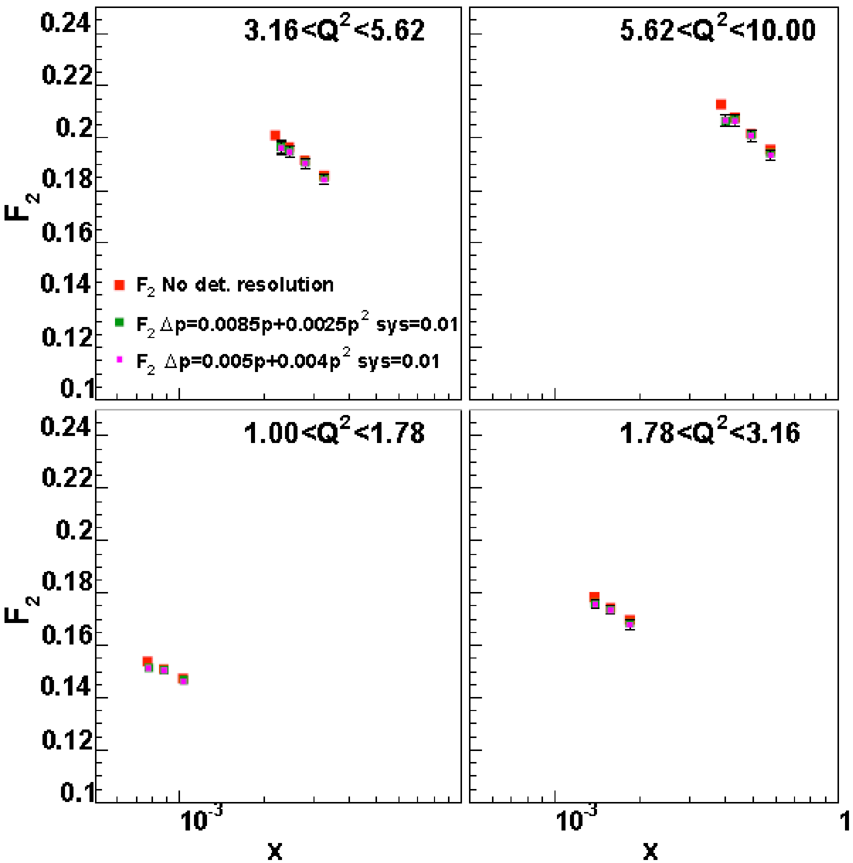
Golden Measurement for Tracking F_L

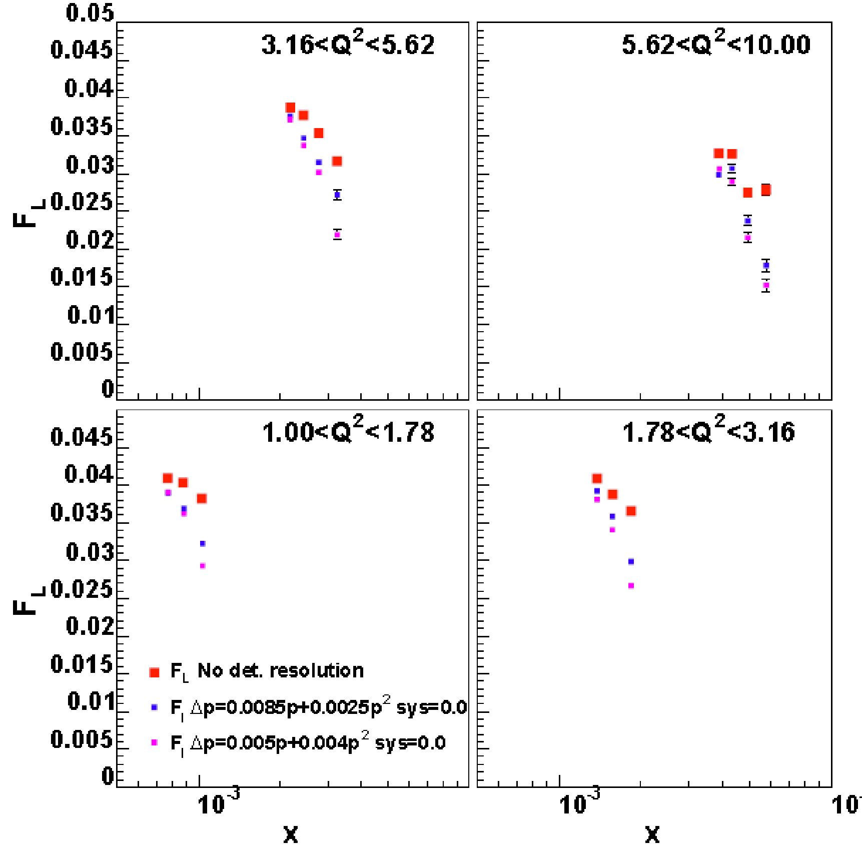
$$\sigma_r(x,Q^2) = \frac{Q^4 x}{2\pi\alpha^2\left[1+(1-y)^2\right]}\frac{d^2\sigma}{dxdQ^2} = F_2(x,Q^2) - \frac{y^2}{1+(1-y)^2}F_L(x,Q^2)$$



- Measurements of F_L are made by varying the beam kinematics so as to inspect the same (x,Q^2) at different y.
- This challenges al aspects of measurement:
  - Varying particle mometa vs h.
  - Resolution.
  - Running time trade-offs.
  - Systematic errors.

Study #1: F_2 & F_L

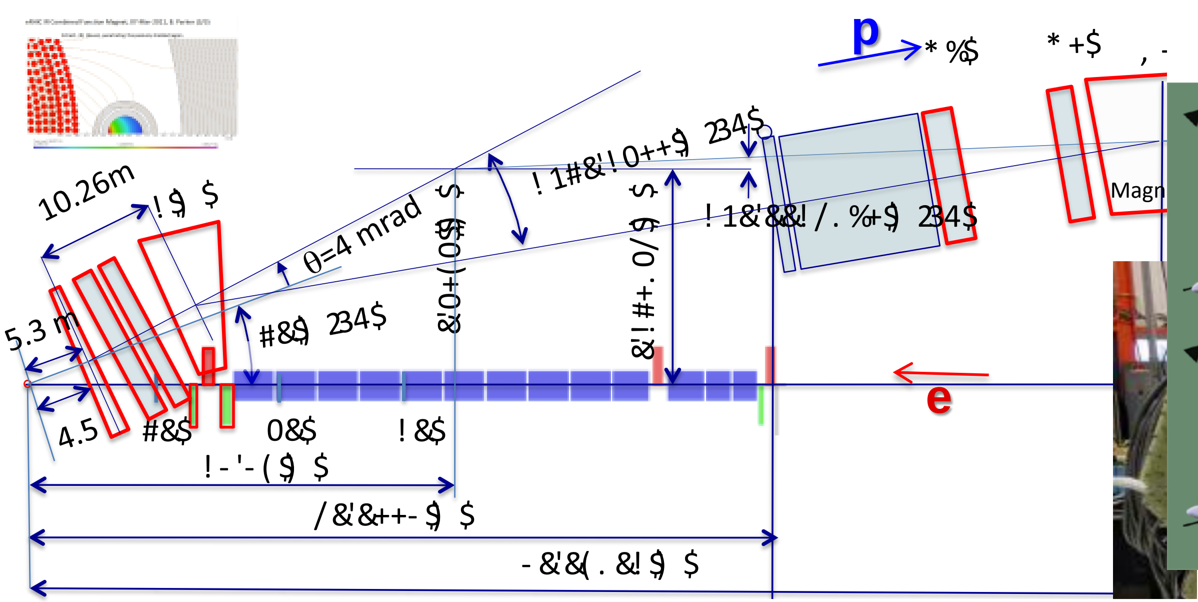


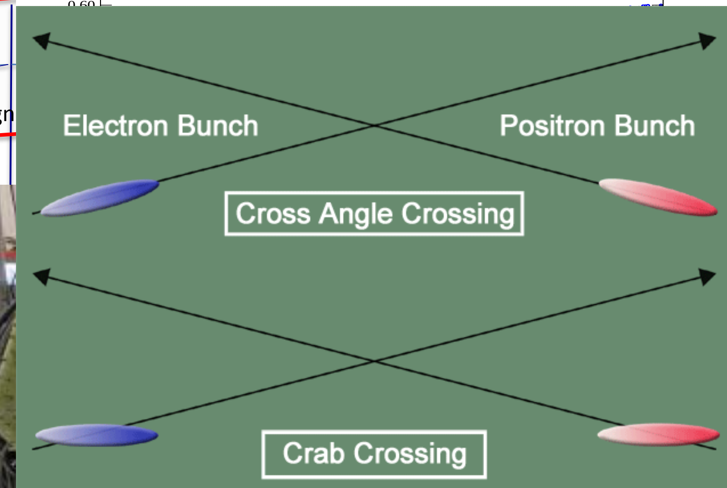


- No correction for detector resolution.
- Demonstrates veracity of F_L as "Golden Measurement".

$$\sigma_r(x, Q^2) = \frac{xQ^4}{2\pi\alpha_{em}^2 Y_+}\frac{d^2\sigma}{dx\,dQ^2} = F_2(x, Q^2) - \frac{y^2}{Y_+}F_L(x, Q^2)$$

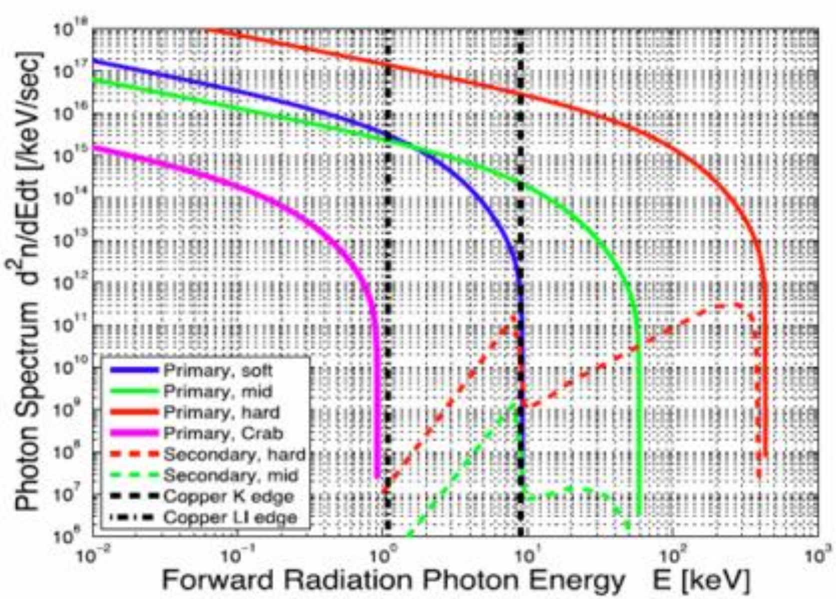
eRHIC high-luminosity IR with β*=5 cm

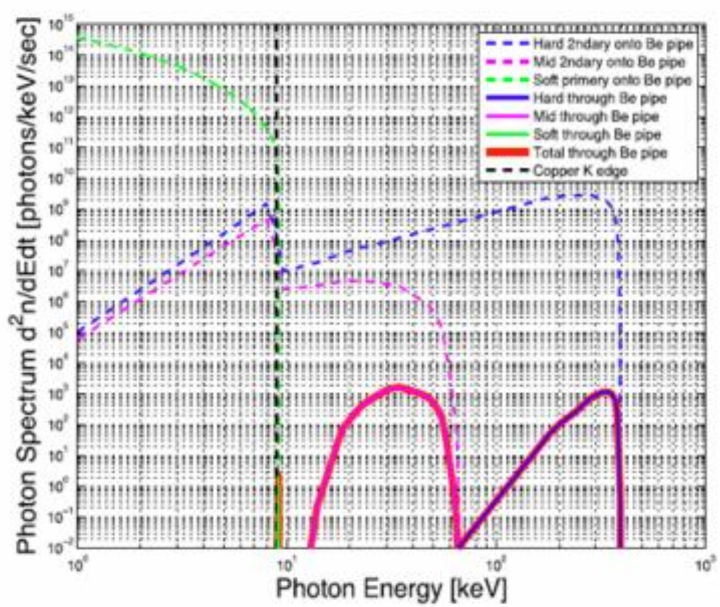




eRH
and

- 1
- H
- A
- I
  a
- G





Future Simulation Work

- Complete the geometry implementation of the detector for the GEANT simulations.
- Implement all IR magnets to allow for tracking of, e.g. the forward going protons from exclusive
- reactions in Roman pots.
- Simulate the impact of synchrotron radiation on the detector.
- Provide results on the following questions:
  - Is the occupancy in the CMOS-pixel μ-vertex tracker small enough that we can track
  - from inside out?
  - Is any intermediate tracking detector needed between the CMOS-pixel μ-vertex tracker and the TPC / Barrel GEM tracker?
  - What is the occupancy for the different CMOS-pixel μ-vertex layers in the barrel and in the forward direction?
  - Is the material budget of a barrel GEM tracker tolerable?
  - What magnetic field is needed given the intrinsic resolutions of a TPC or Barrel GEM tracker and the CMOS-pixel μ -vertex disks and a GEM tracker in the forward direction?
  - Do we have heavy fragments in the direction of the forward CMOS-pixel μ-vertex disks?
  - What is the achievable Q2, x and y resolution for the different tracking solutions?
  - What efficiency and misidentification can be tolerated in hadron (π, K, p) identification?

Budget

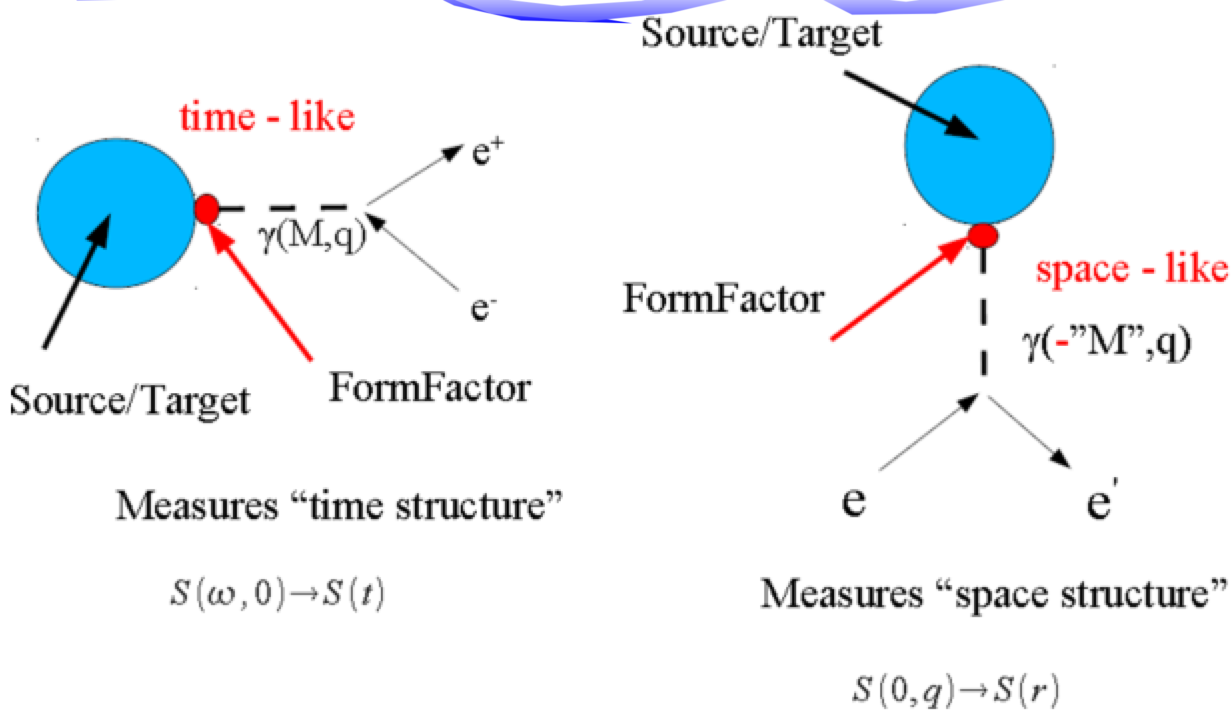
- Request to hire Monte-Carlo software simulation specialist for the next three years.
- Yearly cost:

Item		Costs in $k
Labor Band Salary per year	$60,501 to $89,700	
Salary per year		75.1
Fringe + Overhead		97.6
Total yearly request		172.7

- Request additional support for Cherenkov tests due to evolving scope of the tests and additional infrastructure:

Item	Costs in $k
Equipment (gas lines, cabling, support structures, remote control devices)	10

Primer for Heavy Ion Physicists



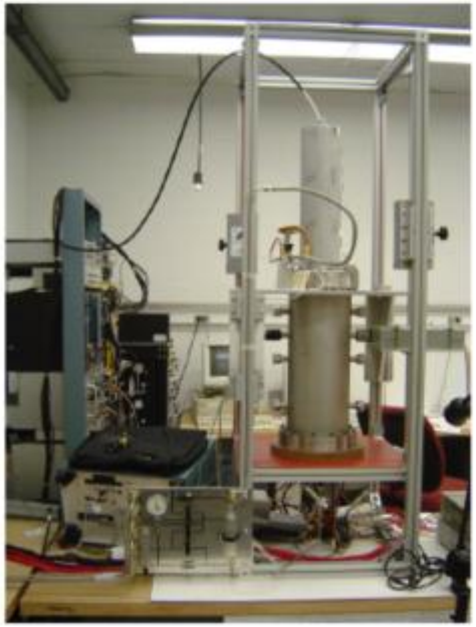
- Much interest in RHI collisions has focused on the measurements of di-lepton emission from the plasma state.
- dilepton production and DIS are simply rotated diagrams.
- One cannot perform DIS on hot QCD matter.
- However, when cold nuclear matter is your interest, DIS is the cleanest and most informative probe.

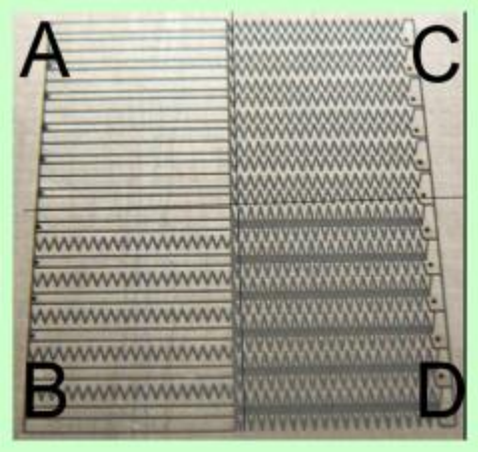
Technology Choices Abound

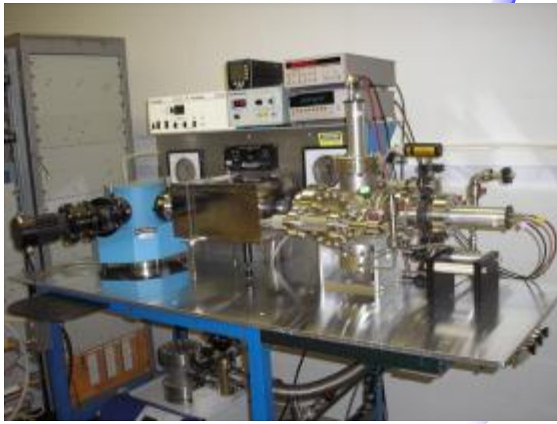
	Forward eta (η>2)	Barrel $\lvert\eta\rvert$<2
Ecal	$PbWO_4$	SciFi & W-powder CsI crystals Shish-kebab
PID	Dual Rad RICH H.R. TOF	Proximity RICH DIRC dE/dx w/ H.R. TOF
Tracking	Silicon MAPS MAPS w/ gas	TPC (long or short) Barrel GEMs MAPS

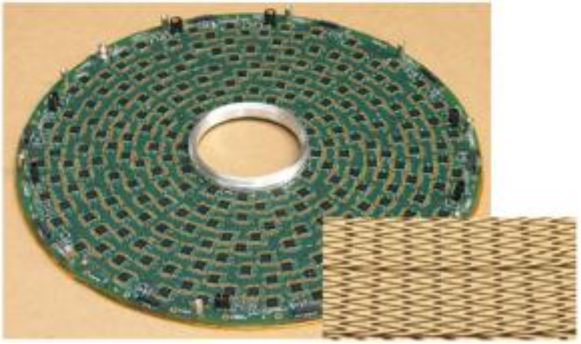
Brookhaven Lab

- Hadron-Blind Detector
- Chevron charge division
- Fast drift/low mass TPC
- ASIC development
- VUV spectrometry

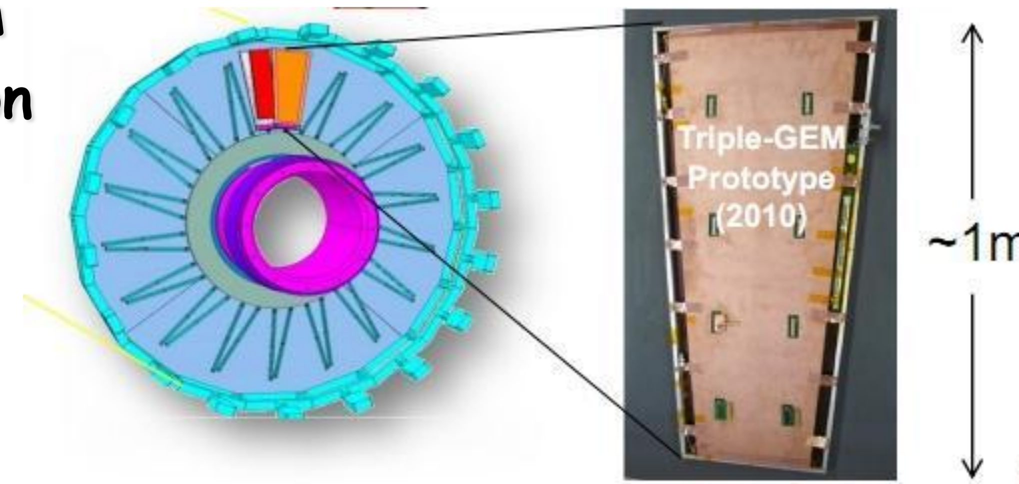








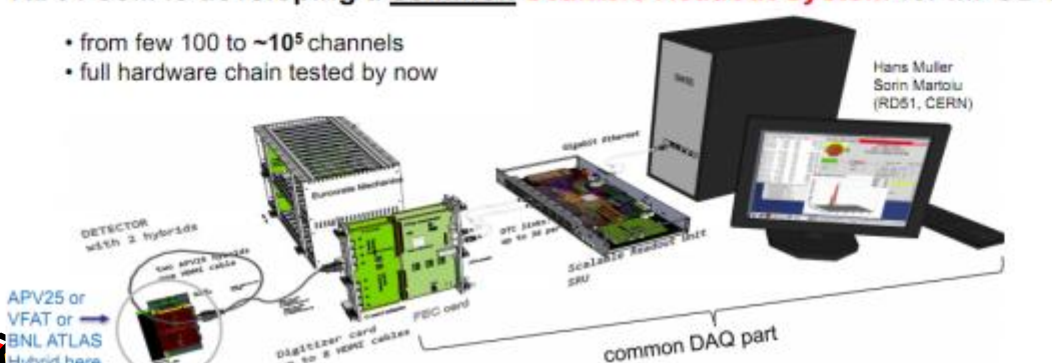
- CMS High-η GEM Upgrade
- RD51 SRS readout System
- Large-Area GEM production



Single-mask GEM cross section

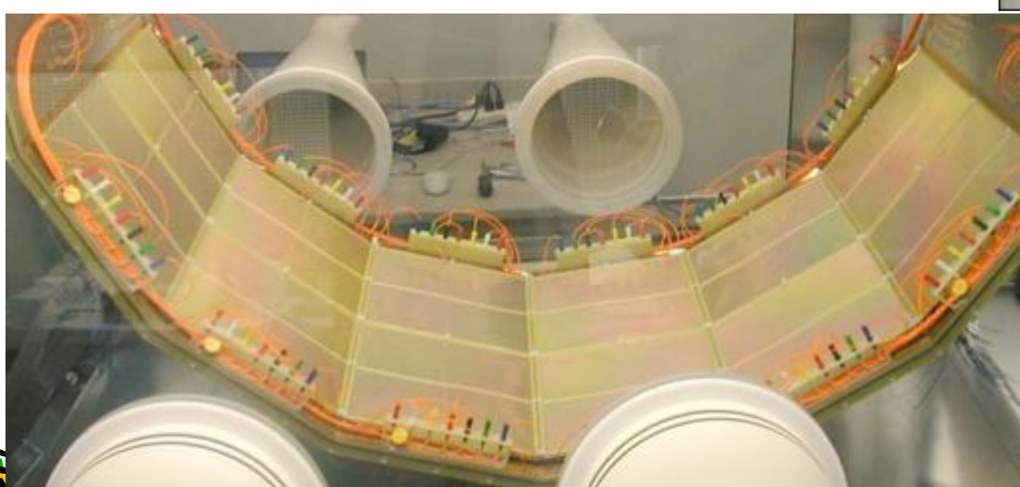
RD51 coll. is developing a common *Scalable Readout System* for MPGD's

- from few 100 to ~10^5 channels
- full hardware chain tested by now



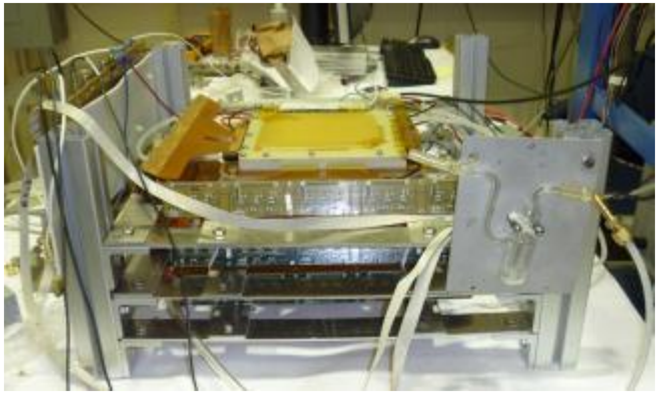
Stony Brook University

- Hadron-Blind Detector
- Large Clean Room
- Gas Chromatography
- CsI Photocathodes

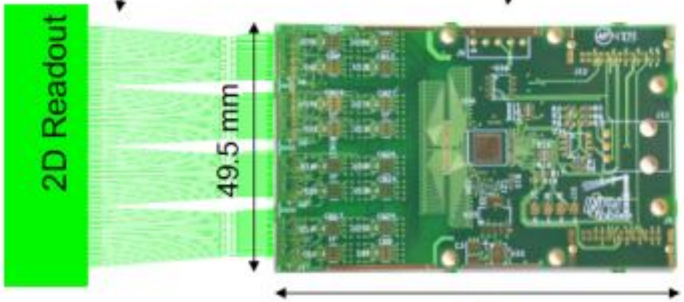


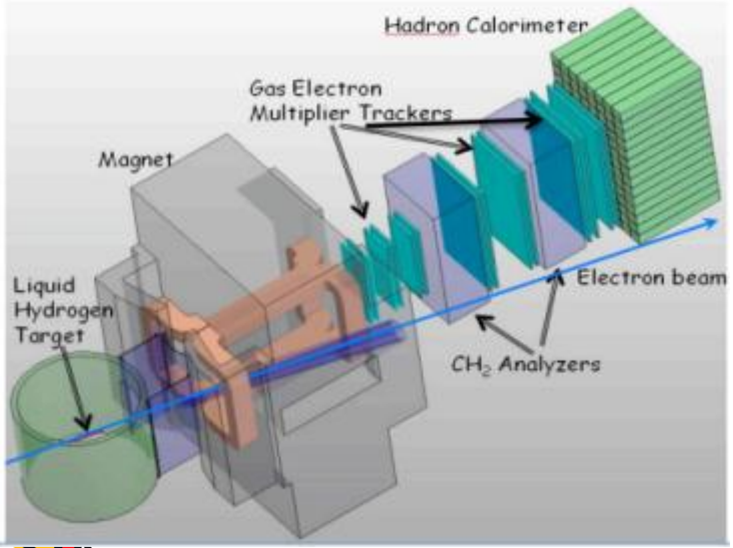
University of Virginia

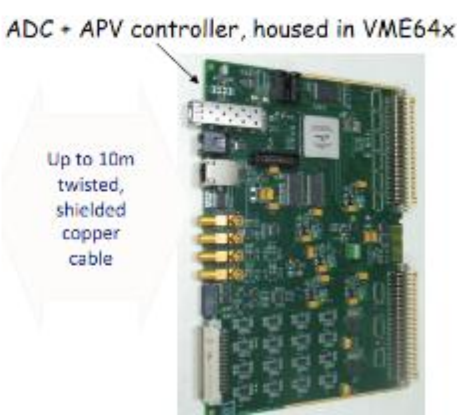
- Prototype GEM tracker tested at Jlab now
- Super Big Bite
- SoLID



prototype tracker prepared for beam test.



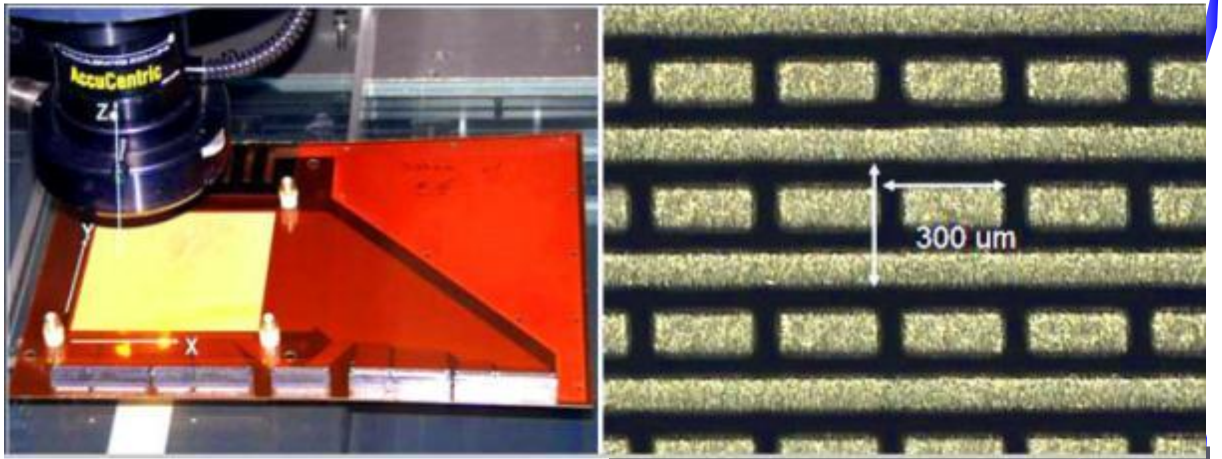


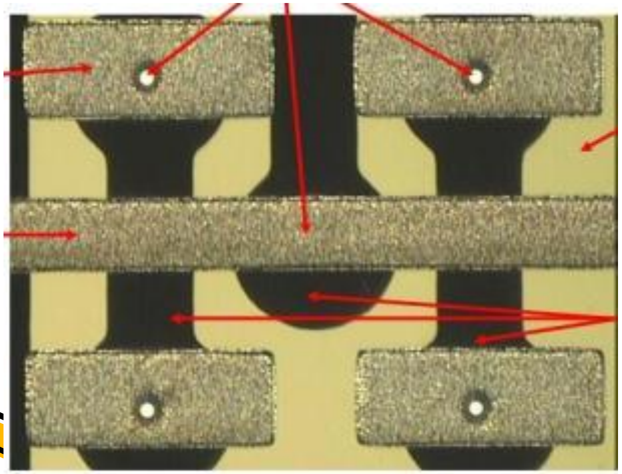


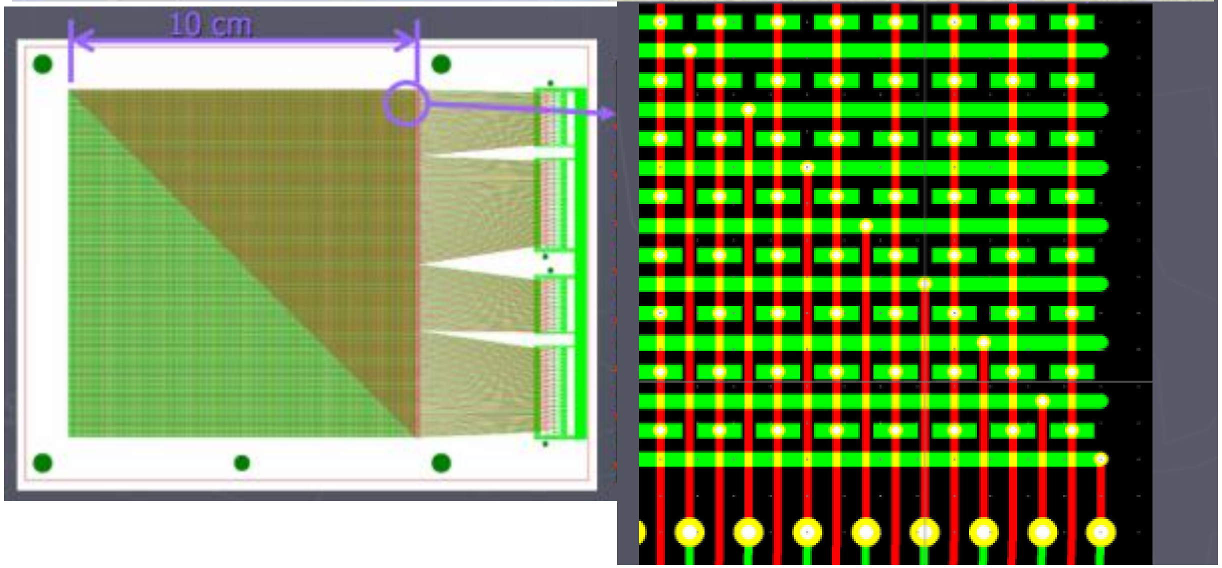
Bigbite MWDC tracker built at UVa.

Yale University

- Forward GEM Tracker
- Developed Strip-pixel readout system.
- Short term proposal:
  - 3-coordinate strip-pixel readout.



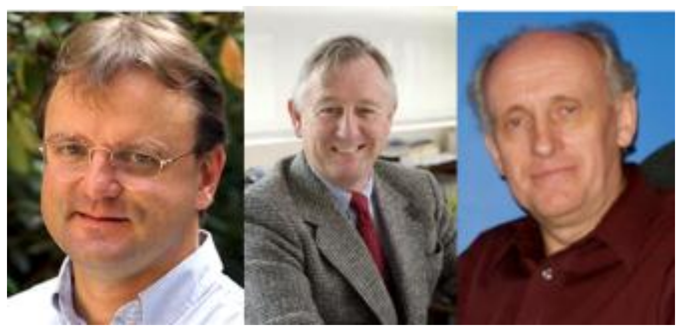




Not requesting funds…

- Iowa State University

- MIT



- Lawrence Berkeley Laboratory

- Los Alamos National Laboratory

Simulation Issues I:

- Material and position resolution budgets:
  - Depends upon source of Q^2.
  - Depends upon measurement channel.
  - Golden channel to push tracking: F_L
- Choices between Fast Drift TPC & GEM tracking outside of the thin micro-vertex tracking layer
  - Nothing is thinner than a TPC.
  - Can have a “thinnest direction”?
  - Can it resolve multiple tracks from overlapping events?
  - Collision rate limitation?
- High performance dE/dx measurements via Cluster Counting.
- What magnetic field configurations could be considered to maintain high performance at high η?
  - Solenoid not optimal for resolution at small angles.

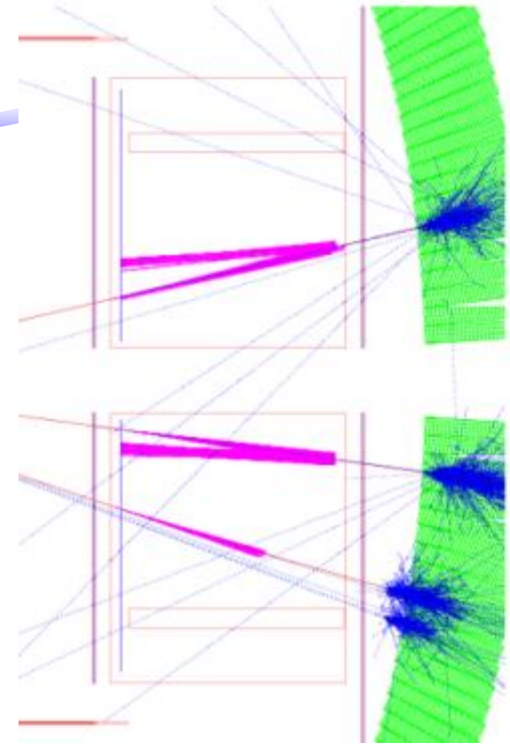
Simulation Issues II:

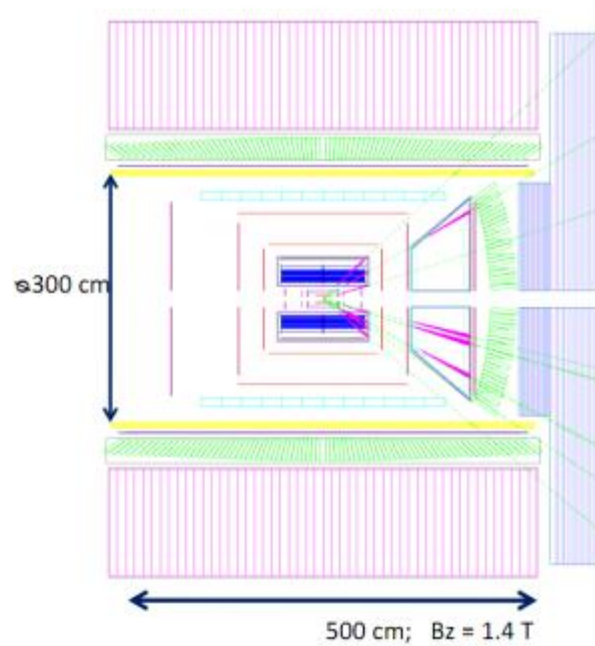
- What form of B-insensitive detector can be used for PID?
  - RICH with various readout choices:
    - CsI photocathode, SiPM
  - High Resolution TOF alone or within RICH
    - SiPM, MCP-PM readouts…
- Proximity-focus RICH in central arm.
  - Can PID momentum-limits be extended via blob-ID??
  - TOF within RICH by RICH
- Limits on Ring radius resolution due to B-field, M-Scat.

The Physics we want to study

- What is the role of gluons and gluon self-interactions in nucleons and nuclei?
  - Observables in eA / ep:
    - elastic/diffractive events: rapidity gap events, elastic VM production, DVCS
    - inclusive events: structure functions F_2^A, F_L^A, F_{2c}^A, F_{Lc}^A, F_2^p, F_L^p,………
- What is the internal landscape of the nucleons?
  - What is the nature of the spin of the proton?
    - Observables in ep
      - inclusive & semi-inclusive events: Asymmetries → polarized cross-sections,
      - inclusive events: electroweak Asymmetries (γ-Z interference, $W^{+/-}$)
  - What is the three-dimensional spatial landscape of nucleons?
    - Observables in ep/eA
      - semi-inclusive events: single spin asymmetries (TMDs)
      - elastic/diffractive events: cross sections, SSA of exclusive VM, PS and DVCS (GPDs)
- What governs the transition of quarks and gluons into pions and nucleons?
  - Observables in ep / eA
    - semi-inclusive events: cross sections, R_{eA}, azimuthal distributions, jets

Simulation framework…





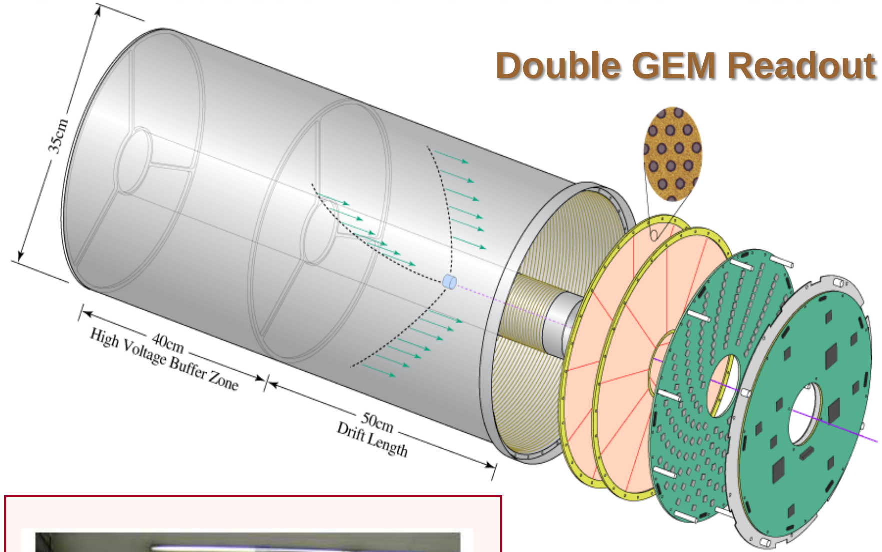
- The most important work over the coming year involves simulations to propose viable technology choices for R&D.
- A simulation framework exists.
- The work plan involves driving processes:
  - F_L drives momentum precision.
  - PID driven by strange particles:
    - Δs measurements
    - Charm via hadrons
- No funds requested for simulations.

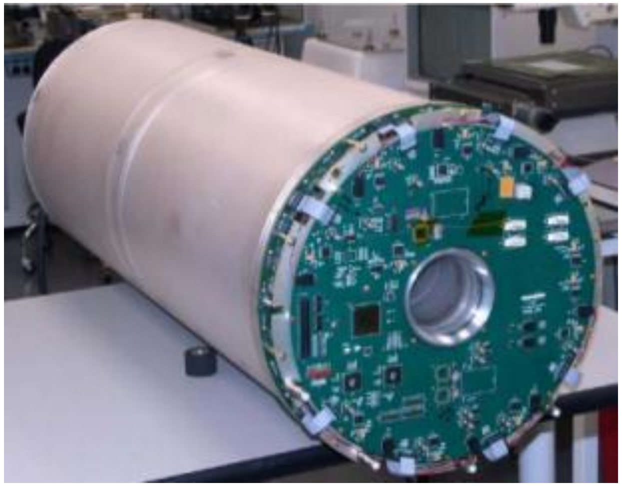
Hardware tasks during 1st year

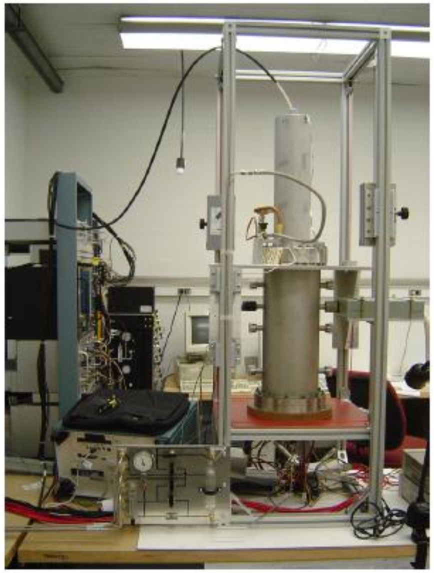
- Measurements of fast TPC performance characteristics.
- Development of very large area GEM detectors.
- Development of GEM-based CsI-photocathode detectors for PID in barrel and endcap.
- Development of methods to minimize electronics-induced gaps in large area GEM detectors.
- Development of a 3-coordinate strip-pixel readout.

Fast Drift TPC Development

GEM Readout TPC for the Laser Electron Gamma Source (LEGS) at BNL



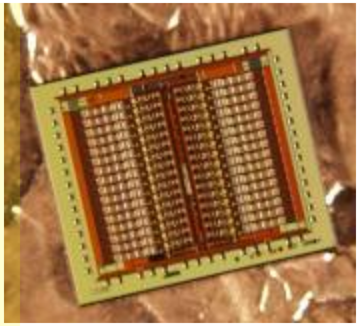




GEM TPC Test Facility in BNL Physics Dept

Designed and built by BNL Instrumentation Division

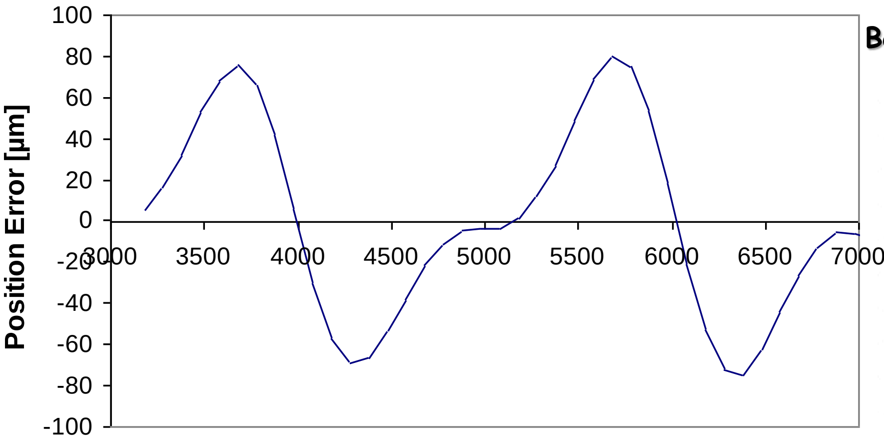
Custom ASIC
- 32 channels - mixed signal
- 40,000 transistors
- low-noise charge amplification
- energy and timing, 230 e^-, 2.5 ns
- neighbor processing
- multiplexed and sparse readout

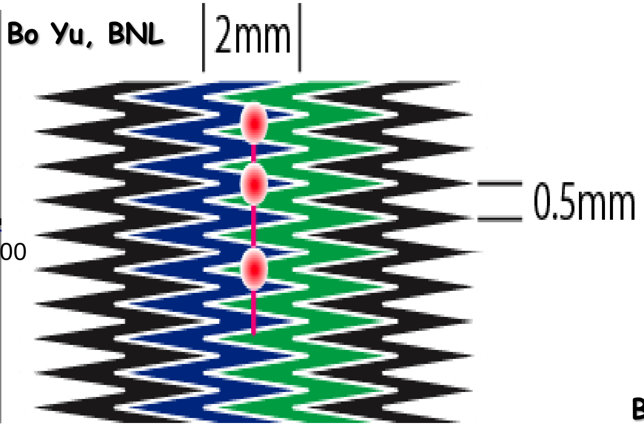


G. De Geronimo et al., IEEE TNS 51 (2004)

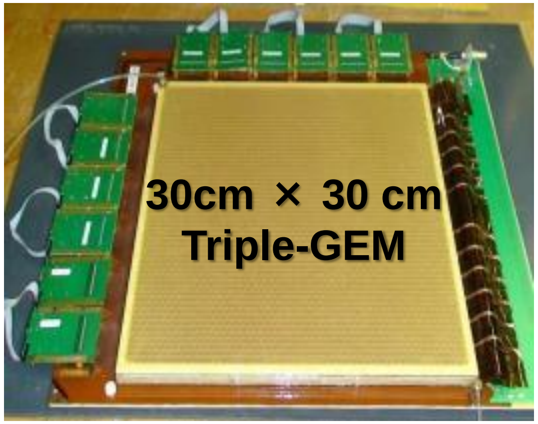
Large-Area Readout Using Zigzag Strips

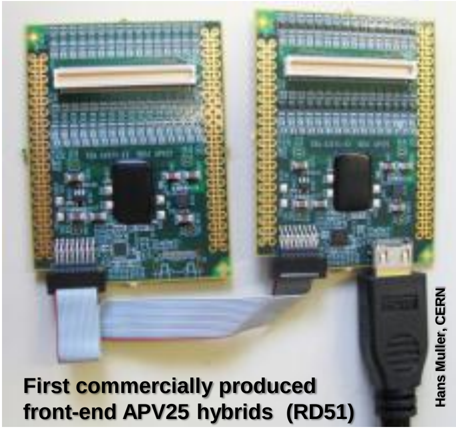
Follow up on previous BNL R&D to reduce required strip & channel numbers. Position errors < 80μm achieved with 2mm strip pitch in small prototypes:





Test performance with medium-size 3-GEM det. using analog SRS readout with APV25 hybrid cards (128 ch. per card) at BNL & Florida Tech

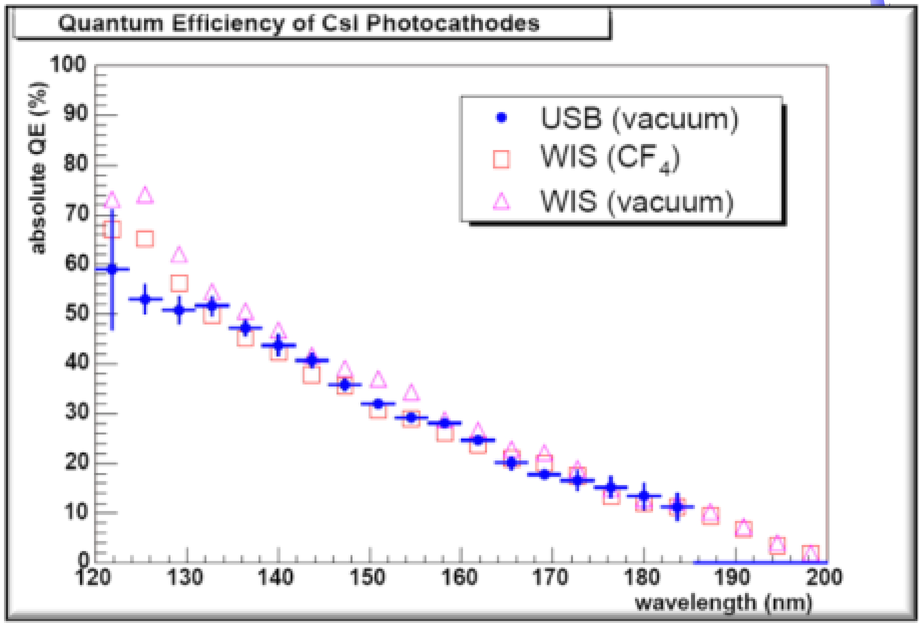




First commercially produced front-end APV25 hybrids (RD51)

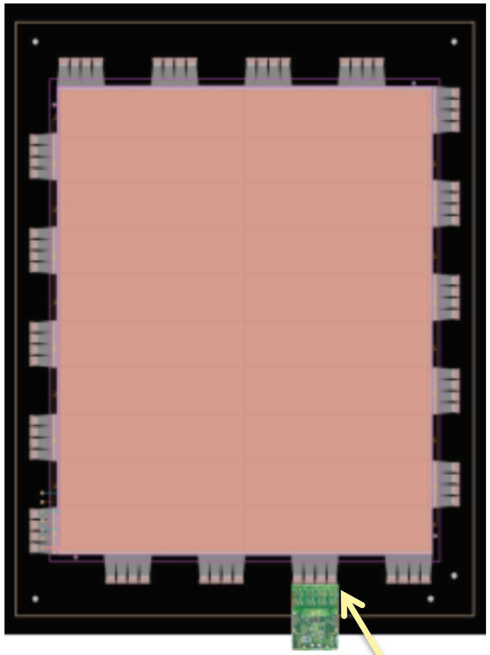
CsI Photocathode Research

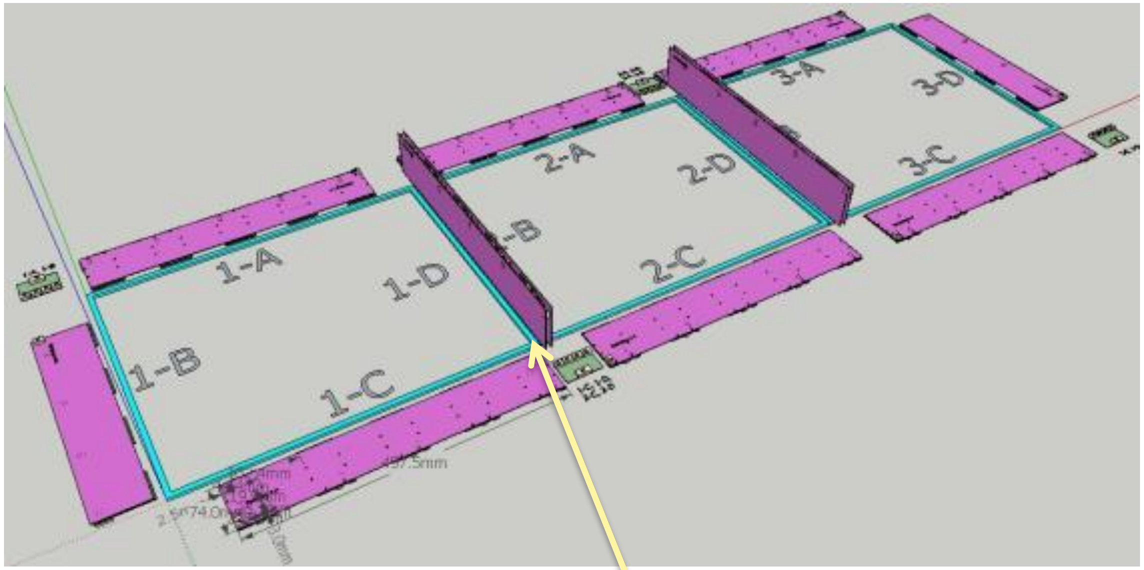
- The Stony Brook group wishes to investigate the feasibility of CsI-coated GEMs as a large area, B-field tolerant solution for RICH work.
- Operating in CF_4 the PHENIX HBD detector demonstrated the highest measured N_0 (327) of any large Cherenkov Detector.
- However, there are limitations due to the sensitivity range of CsI (110 – 200 nm).
  - Windows provide provide higher cutoff.
  - Most (not all) optics for reflection provide higher cutoff.
  - Aerogel opaque in sensitive range.



Large Area GEM w/ "hidden" Readout

- EIC requires large area GEM coverage: disks with radii up to ~ 2m
- Single mask technique, GEM splicing: GEM foils up to 2 m x 0.5 m.
- Large area coverage requires segmentation with narrow dead areas
- Optimized for the large GEM chambers of Super-Bigbite



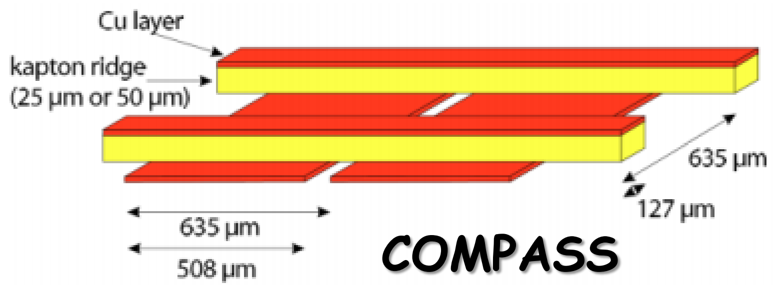


Readout cards perpendicular to the active area

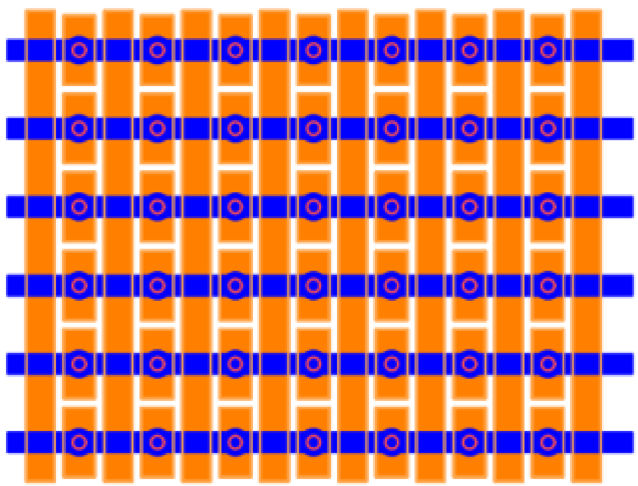
Flexible extensions of readout-board: directly plug in the front end card

- R&D proposal: build a 1 m x 0.9 m prototype with two segments.

Strip-pixel R&D

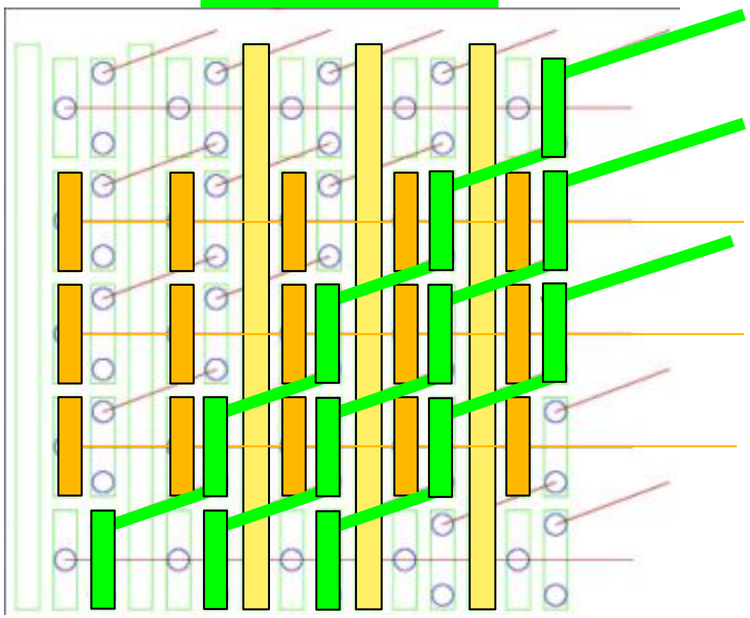


COMPASS



STAR FGT

PROPOSED



- Position by charge division (~100 µm).
- Readout count set by occupancy:
  - 2D uses X-Y charge matching allows up to 10 particles per "patch"
  - 3D uses chg & GEOMETRY matching requires R&D to determine limit.

NOTE: Redundancy "hardens" detector against failure.

Budget Summary

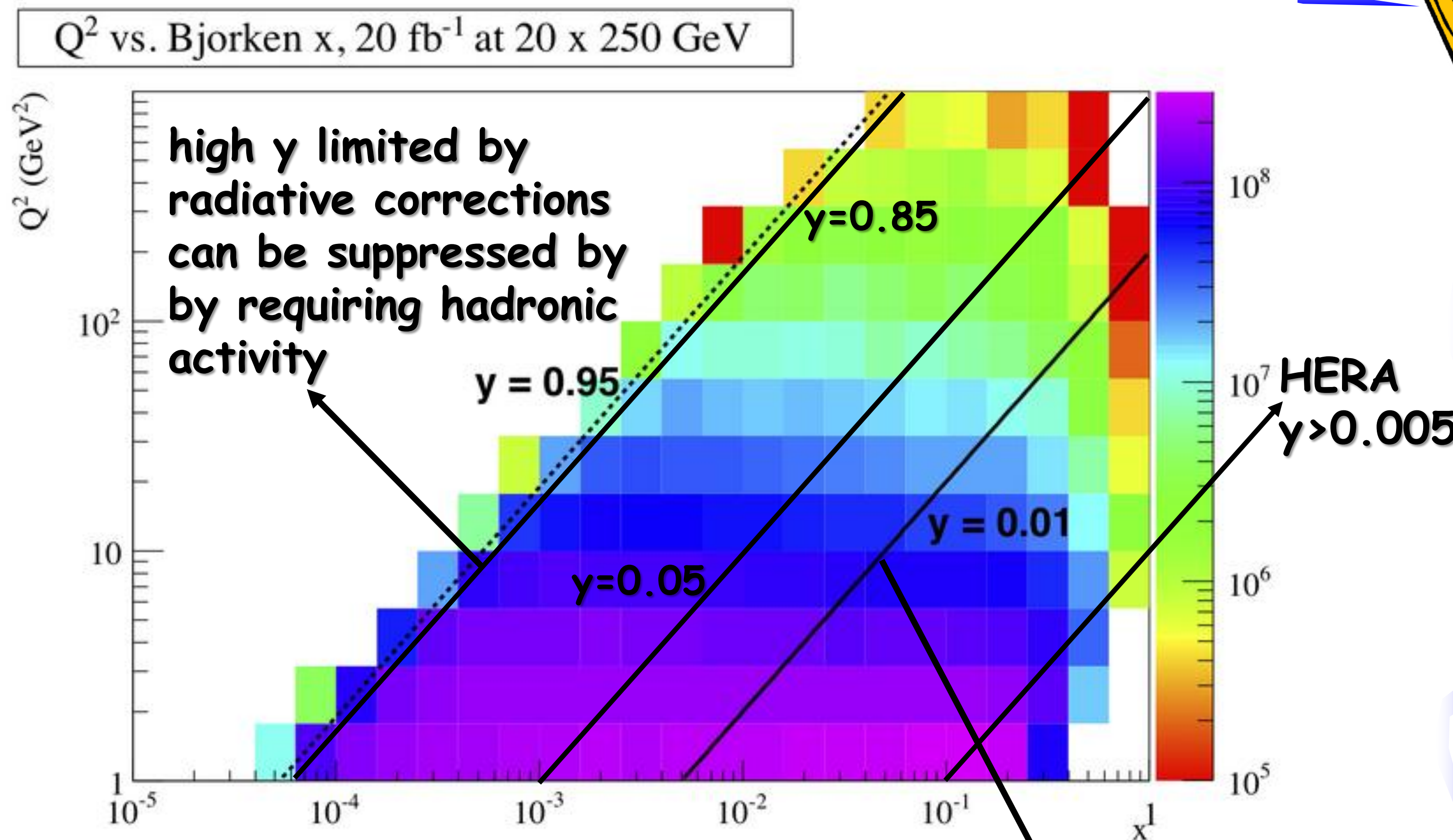
- The budget consists of a set of so-called "seed grant" projects that are likely interesting to pursue regardless of the findings of our physics/simulations work.

Item	k$
Fast Drift TPC	40
Zig-Zag Readout	26
Large Area GEM w/ Hidden Readout	45.6
CsI-coated GEMs for PID	50
Strip-pixel Readout	39.9
TOTAL	201.5

Summary

- A Large and growing group of scientists have already begun to work on determining specific and integrated proposals of tracking and PID for the EIC.
- A list of small seed projects relevant to the later work is included in the letter of intent.
- The principle deliverable from this work will be a specific research plan within one year's time leading to a specific and realistic tracking and PID scheme for meeting the physics goals of EIC.

DIS Kinematics



low y limited by theta resolution for e'
→ use hadron method

- Strong x-Q^2 correlation
  - high x → high Q^2
  - low x → low Q^2

Important for Detector Design

- Detector must be multi-purpose
  - One detector for inclusive (ep -> e'X), semi-inclusive (ep->e'hadron(s)X), exclusive (ep -> e'πp) reactions in ep/eA interactions
  - run at very different beam energies (and ep/A kinematics)

    $E_{p/A}/E_e \sim 1 - 65 \rightarrow$ HERA: 17 – 34; lepton beam energy always 27GeV
- Inclusive DIS:
  - with increasing center-of-mass energy lepton goes more and more in original beam direction
  - high Q^2 events go into central detector
  - low Q2 events have small scattering angle and close to original beam energy

    need low forward electron tagger for low Q^2 events

    low-mass high resolution trackers over wide angular acceptance
- Semi-Inclusive DIS
  - hadrons go from very forward to central to even backward with lepton beam energy increasing

    good particle-ID over the entire detector
- Exclusive Reactions:
  - decay products from excl. ρ / ϕ / J/ψ go from very forward to central to even backward with lepton beam energy increasing

Additional Remarks

- Charm detection
  - structure functions
    - detecting lepton form decay in addition to scattered via displaced vertex should be enough
  - charm in fragmentation
    - need to reconstruct D^0 meson completely to measure its z
      → good PID

- Very high luminosity 10^{34} $cm^{-1}s^{-1}$
  - will be systematic limited in many measurement
  - needs a lot of care to account for this in the design
    - detector: alignment, ……
    - polarization measurements
    - luminosity measurement

Budget

- The budget consists of a set of so-called "seed grant" projects that are likely interesting to pursue regardless of the findings of our physics/simulations work.

Item	Cost ($k)
Materials (GEMs, readout boards, etc)	8
Gas system components	8
Electronic components	5
Expendables (gas)	5
Total	**26**
Overhead (1.52)	14
Total budget request	**40**

Item	Cost ($k)
GEM foils	20
Readout planes	10
Chamber planes and mechanics	10
GEM chamber supplies	5
Undergraduate student	5
Total	50

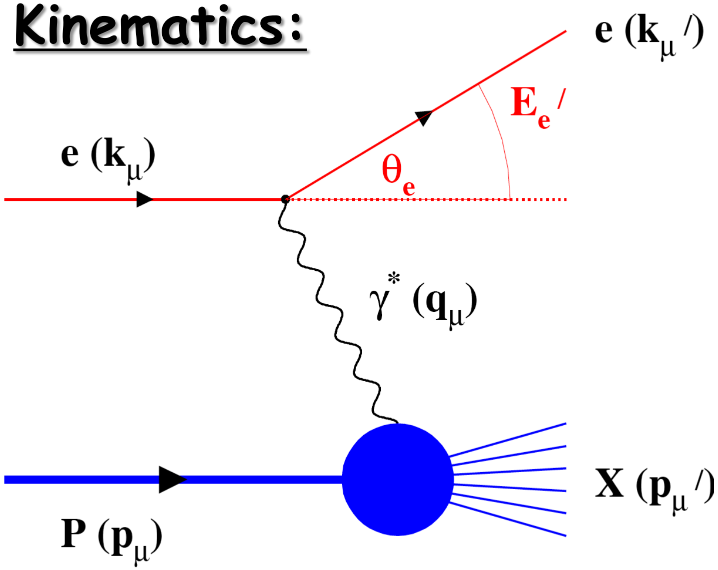
Item	Cost ($k)
10 cm × 10 cm PCBs with zigzag readout for use in CERN standard GEMs	5
Small Amptek Mini-X X-ray generator for testing under medium rates	7
30 cm × 30 cm 4 GEM foils and 1 drift foil	5
30 cm × 30 cm GEM spacer frames with ribs	2
30 cm × 30 cm PCB with zigzag readout strips	4
Gas (Ar/CO_2 80:20)	1
Miscellaneous materials (cables, pipes, etc.)	1
Overhead (1.48 on gas and materials only)	1
Total budget request	26

Item	Cost ($k)
Custom made GEM foils matching focal plane area	10
Readout PCB	4
Electronics & DAQ	10
Liquid radiator	6
Sum	30
Overhead (1.52)	15.6
Overall request	45.6

Item	Cost ($k)
1. GEM Chamber	
1.1 GEM foils	5
1.2 Mechanical (frames, gas enclosure, HV distribution board)	3
2. Readout Board	
2.1 NRE for 2 versions	2.5
2.2 Boards (6 of ea. Version)	5.4
3. Readout Electronics	
3.1 APV Readout system	17
3.2 Interface and DAQ	6
4. Operating	
4.1 Gas	1
Total budget request	**39.9**

Deep Inelastic Scattering

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e(1-\cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

***Hadron*:**

$$z = \frac{E_h}{\nu};\ p_t \text{ with respect to } \gamma$$

Inclusive events:

e+p/A → e'+X

detect only the scattered lepton in the detector

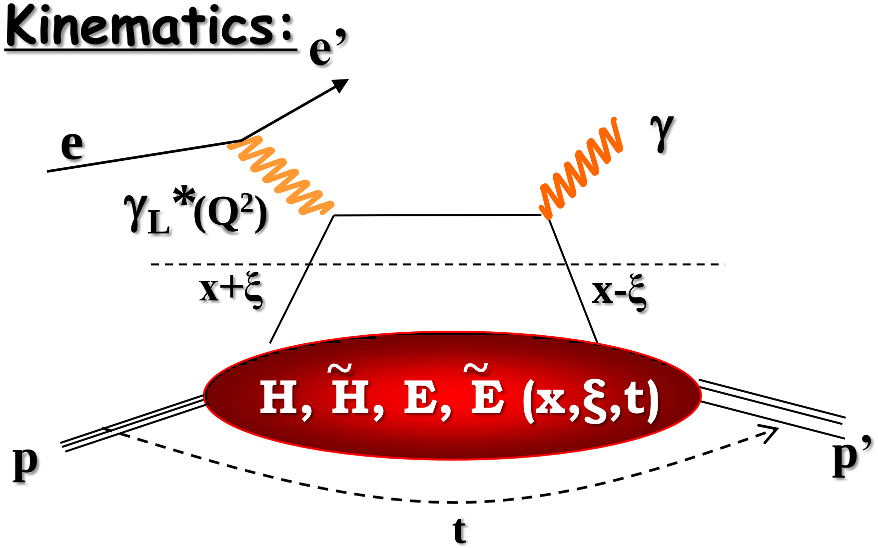
Semi-inclusive events:

e+p/A → e'+h(π,K,p,jet)+X

detect the scattered lepton in coincidence with identified hadrons/jets in the detector

Deep Inelastic Scattering

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e (1 - \cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

$$t = (p - p')^2, \xi = \frac{x_B}{2 - x_B}$$

Exclusive events:

e+p/A → e'+p'/A'+γ / J/ψ / ρ / ϕ

detect all event products in the detector

Special sub-event category rapidity gap events

e+p/A → e'+γ / J/ψ / ρ / ϕ / jet

don't detect p' → HERA: 20% non-exclusive event contamination

missing mass technique as for fixed target does not work